THE

AËRONAUTICAL JOURNAL.

(FOUNDED 1897 in succession to the ANNUAL REPORTS).

THE ORGAN OF THE ROYAL AËRONAUTICAL SOCIETY.

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Edited for the Council by J. LAURENCE PRITCHARD, Associate Fellow.

All communications should be addressed to the Editor.

No. 123. MARCH, 1921. VOL. XXV.

Notices of the Royal Aëronautical Society.

Election of Members.

The following members were elected at a Council Meeting held on Tuesday, February 15th, in the various grades as shown :—

Associate Fellows.—Flying Officer G. Mornington Bryer, A.F.C., J. D. Campbell, B.Sc., H. B. Wyn Evans, M.I.N.A., Shou-Heng-Huang, Flight Lieut. A. J. Osborn, Lieut. C. St. Clair Penny, Squadron Leader R. G. Parry, D.S.O., E. T. Robins.

Students.—A. N. Clifton, C. Daniel, E. M. Farris, W. H. Rossiter, V. S. Thompson, M. W. Wood.

Foreign Members.—R. A. Hendy, Lieut.-Col. H. St. Clair Smallwood, R.A.F.

Lectures.

The remaining lectures of the present Session will take place as follows :—

March 3rd.—"Parachutes," by Major T. Orde-Lees, O.B.E., A.F.C.; "Airship Fabrics," by Mr. J. W. W. Dyer; Chairman, Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C., Associate Fellow.

March 17th.—"Flying Boat Construction," by Capt. D. Nicolson, Associate Fellow.

Obituary.

It is with great regret that the death of Colonel James Smith Park, M.V.O., is announced. Colonel Smith Park was one of the most active members of the Committee of the Scottish Branch, on which he had served since its inception.

New Member of Council.

A letter of resignation from the Council was received at the February Council Meeting from Lieut.-Colonel A. Burgoyne, M.P. It was decided to accept Col. Burgoyne's resignation with great regret, and Colonel the Master of Sempill, A.F.C., was unanimously co-opted to serve in his stead pending the next elections.

Council.

At their last meeting the Council completed their consideration of the Secretary's draft amendments to the Rules which will now, together with the new

regulations for the admission of Fellows and Associate Fellows, be laid before the Annual General Meeting for adoption at 5.0 p.m. on Thursday, March 31st.

The statement of accounts for the six months ending December 31st, 1920, was also passed at the same meeting, and these, together with the Council's Annual Report on the state of the Society, will be found on another page.

Early History.

The Secretary is glad to be able to announce that he has been able lately to obtain two copies of the first paper to be read before the Society on its formation, which he has placed in the Library. This was a paper read by Mr. Fred Brearey, the original Honorary Secretary, at Stafford House, on February 28th, 1866, when the Duke of Sutherland occupied the Chair. The occasion was the second Council Meeting (the first having been held at Argyll Lodge on January 12th of the same year), and the paper contains a suggested programme for the proceedings of the Society. The order for its printing and circulation to members has been found in the original minute book in the Society's possession. It is a paper-bound pamphlet of 4 octavo pages, and is believed to be very rare. The Secretary had already a copy in his own possession, but had not previously been able to trace one among the Society's records. He feels that members will be glad to have this interesting historical addition to the Library. The first paper read before a meeting of the members as a whole was, of course, F. H. Wenham's paper on "Aerial Locomotion," read at the Royal Society of Arts on June 27th, also in 1866, which has been reprinted as the second volume of the "Aeronautical Classics."

Donations.

The Council desire to acknowledge with grateful thanks the gift from Mrs. Lawrence Hargrave of a large number of note-books, papers, negatives and lantern slides belonging to her late husband. Lawrence Hargrave did a large amount of most valuable experimental work in Australia, mainly in connection with kites, between the years 1884 and 1908, and is deservedly considered one of the most important early pioneers of aviation. He was born on January 29th, 1850, and died on July 6th, 1915. Arrangements have been made for these records to be carefully gone through with a view to the extraction of any data which should be put on historical record and which has not been previously published.

The Council desire also to acknowledge the receipt from Mr. Alma Baker, Honorary Member, of a presentation copy of his "Souvenir of the Australian and Malaya Battleplanes, 1914-1918," which has been prepared as a record of the efforts made to assist the Home Government during the war by presenting aeroplanes to the Royal Flying Corps and Royal Air Force, as a result of which sufficient money was subscribed to purchase 94 aeroplanes.

Manchester Association of Engineers.

At the request of the Manchester Association of Engineers, it has been arranged for the Chairman (Air Commodore H. R. M. Brooke-Popham, C.B., C.M.G., D.S.O., A.F.C.) to read a paper on "Some Problems in the Design and Operation of Aircraft" before the members of that body at 7.0 p.m. on Wednesday evening, March 2nd.

Journal.

Copies of the following numbers of the Journal are urgently required, and the Secretary would be grateful if any member who does not desire to retain his copies for filing purposes would be kind enough to return them as these numbers are quite out of print:—January, March, April and June, 1920.

Library.

The following books have been placed in the Society's Library :—" Applied Aerodynamics " by Dr. L. Bairstow, and " The Design of Screw Propellers for Aircraft " by Dr. H. C. Watts.

Membership Cards.

Cards of membership are being enclosed in the envelopes containing the notice of the Annual General Meeting to each member who has paid his subscription. Those who have not yet forwarded their subscriptions for this year will receive cards on receipt of the amount due.

Arrangements for the Month.

March 2nd, 7.0 p.m.—Chairman's Lecture on " Some Problems in the Design and Operation of Aircraft " before the Manchester Association of Engineers.

March 3rd, 5.0 p.m.—*Lectures* : " Parachutes " by Major T. Orde-Lees, O.B.E., A.F.C. ; " Airship Fabrics " by Mr. J. W. W. Dyer.
Chairman : Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C.

March 15th, 4.0 p.m.—Lectures and Publications Committee Meeting.

,, ,, 4.30 p.m.—Candidates Qualifications Committee.

,, ,, 5.0 p.m.—Council Meeting.

March 17th, 5.30 p.m.—*Lecture* : " Flying Boat Construction " by Capt. D. Nicolson, Associate Fellow.

March 31st, 5.0 p.m.—**Annual General Meeting** in the Society's Offices.

W. Lockwood Marsh, *Secretary.*

THE ROYAL AERONAUTICAL SOCIETY.

Annual Report of the Council, 1920-21.

In presenting their 56th Annual Report the Council have the honour to announce that during the year His Royal Highness the Duke of York, K.G., graciously consented to become an additional Patron of the Society. Air-Marshal Sir Hugh Trenchard, Bart., K.C.B., D.S.O., and Commander J. C. Hunsaker, U.S.N. (C.C.), were elected Honorary Fellows in June. The Council for the year consisted of the following members :—

Chairman : Air Commodore H. R. M. Brooke-Popham, C.B., C.M.G., D.S.O., A.F.C.

Vice-Chairman : Brigadier-General R. K. Bagnall-Wild, C.M.G., C.B.E.

Mr. A. E. Berriman, Major F. H. Bramwell, Lieut.-Col. A. H. Burgoyne, M.P., Wing Commander Cave-Browne-Cave, C.B.E., Sir Mackenzie Chalmers, K.C.B., C.S.I., Sir Robert Hadfield, F.R.S., Prof. B. Melvill Jones, A.F.C., Major A. R. Low, Lieut.-Col. A. Ogilvie, C.B.E., Lieut.-Col. M. O'Gorman, Mr. F. Handley Page, C.B.E., Mr. A. J. Sutton Pippard, D.Sc., Mr. A. V. Roe, O.B.E., Major-General Sir R. M. Ruck, K.B.E., C.B., C.M.G., Lieut.-Col. H. T. Tizard, A.F.C., Mr. G. Holt Thomas, Brig.-Gen. J. G. Weir, C.M.G., Major H. E. Wimperis, O.B.E.

Honorary Treasurer : Mr. A. E. Turner.

Lieutenant-Colonel the Master of Sempill, A.F.C., was co-opted a Member in place of Lieutenant-Colonel A. Burgoyne, M.P., resigned, in January. Major-General Sir R. M. Ruck, K.B.E., C.B., C.M.G., was elected Vice-President of the Society in November.

The Council feel that they may congratulate Members on the well-being of the Society in spite of the difficulty of the period which is being passed through. There is little doubt that its status has steadily improved during the year, although activities have been necessarily restricted owing to the serious financial position which was disclosed at the beginning of the year. The present situation in this regard is dealt with in some detail in a later paragraph, but it may be said here that the condition of affairs is very considerably improved as a result of making every effort to exercise economy, and that the future may be faced with some confidence in the belief that before the end of the coming financial year the Society will definitely have been placed on a sound financial basis so far as current expenses are concerned, though this means that no increase in the present limited activities can take place. It has at the same time, however, been found necessary to bring forward a deficit in the Balance Sheet of £1,542 19s. 11d. There is every reason to hope that in future it will be possible to make the revenue cover expenditure, but there is no doubt that the financial position will not be thoroughly satisfactory until an Endowment Fund, amounting to some £2,000, has been raised, and the advisability of opening a subscription list to this end is under consideration.

In spite of the necessity for economy, the year has seen a revival of certain methods of bringing members closer together by the holding of an Annual Dinner, at which the President took the Chair, and by the arranging of a visit to the Aerodynamics' Department of the National Physical Laboratory. The provision of a room for the use of members at the Olympia Aero Show also proved of convenience to members visiting the Show.

Membership.

In spite of the increase of subscriptions, by 50 per cent. in the case of old members and by 100 per cent. in the case of members elected subsequent to June 1st, 1920, the membership has been well maintained. This numbered 1,146 in January, 1920, and on January 1st, 1921, stood at 1,002. A gratifying feature is that although inevitably a number of members have found themselves compelled to resign owing to the necessity of cutting down their subscription lists, there is a steady inflow of new members in all grades numbering from 10 to 15 per month.

Scottish Branch.

The membership of the Scottish Branch numbered 156 on January 1st, 1920, and the year has been one of considerable activity, of which a full report was published in the October number of the AERONAUTICAL JOURNAL. A large number of valuable lectures have been given, at which the average attendance has been about 175. The members also paid a visit to Messrs. Beardmore's airship shed at Inchinnan during the autumn, when they had an opportunity of inspecting the rigid airship R.36 under construction. The Chairman of the Scottish Branch, Lord Invernairn, received the honour of elevation to the Peerage in the 1921 New Year's Honours List. The Annual Dinner in London in November afforded a welcome opportunity for members in England to meet the members of the Scottish Branch, who were well represented on that occasion. The Council desire to express their gratitude to the members of the Scottish Executive for their untiring efforts to further the objects of the Society in the North, which have been rewarded by such remarkable success and enthusiasm. It is hoped to publish in a forthcoming number of the Journal the Second Annual Report of this Branch, whose year terminates on May 31st.

Cambridge University Aeronautical Society.

The Council would like to take the opportunity of offering their congratulations to the Cambridge University Aeronautical Society, which became affiliated to the Royal Aeronautical Society during the year, on the remarkable success they have achieved in forming so flourishing a Society in Cambridge. Their lecture programme during the year has been one of the greatest interest and importance, to which a number of technical members of the Society have contributed, and the Cambridge Society is much to be congratulated on the enterprise and enthusiasm of their President (Mr. H. A. Mettam) and Secretary (Mr. O. E. Simmonds).

The Technical Terms Committee.

With a view to better co-ordination, and also owing to a difficulty in providing the necessary money for printing and circulating a revised edition of the "Glossary of Aeronautical Terms," it was in November decided to offer the services of the Society's Technical Terms Committee to the British Engineering Standards Association for the purpose of completing the revision of the Glossary. The Council are indebted to the Association for willingly falling in with the suggestion made, and this Committee is now working under the auspices of that body. It has been arranged that full acknowledgment of the work of the Society shall continue to appear in the new edition of the Glossary.

Representation on Other Bodies.

The Council desire to tender their thanks to the following gentlemen for kindly consenting to serve as the Society's representatives on other bodies:—

Conjoint Board of Scientific Societies.—Major-General Sir R. M. Ruck.
Aeronautical Research Committee.—Lieut.-Col. A. Ogilvie.

Advisory Committee on Aeronautical Education.—Dr. R. Mullineux Walmsley.
British Engineering Standards Association.—Lieut.-Col. M. O'Gorman.
Air Ministry Load Factor Committee.—Lieut.-Col. M. O'Gorman and Capt. G. de Havilland.
British Science Guild.—Major A. R. Low.

Lectures to Other Bodies.

During the year a number of lectures on aeronautical subjects have been arranged by the Society to other bodies both in London and the provinces. A course of six lectures on "Aircraft Steels and Materials" was delivered to the students of Sheffield University during October and November by Brigadier-General Bagnall-Wild, Dr. L. Aitchison, Captain W. A. Thain, Mr. A. J. Rowledge, and Mr. A. A. Remington. Two popular lectures on the development of commercial aeroplanes and airships were delivered in the Fulham Public Library at the request of the Fulham Borough Council in November and February by Captain F. M. Green and the Secretary respectively. At the request of the Higher Production Council, two lectures were delivered at Olympia in February during the "Daily Mail" Efficiency Exhibition by Mr. H. White Smith on "Commercial Aeroplane and Seaplane Transport," and by Mr. C. I. Campbell on "Commercial Airship Transport." The Chairman also delivered a lecture on "Some Problems in the Design and Operation of Aircraft" before the Manchester Society of Engineers on March 2nd, 1921.

At the request of the Air Ministry the Society arranged a series of lectures at the Aero Show at Olympia in July by Captain P. D. Acland, Mr. Griffith Brewer, Captain F. M. Green, Captain D. Nicolson, Flight-Lieut. J. E. M. Pritchard and Major H. E. Wimperis.

The Council desire to express their thanks to all these gentlemen for kindly giving their services on these occasions.

Wilbur Wright Lecture.

The annual Wilbur Wright lecture was delivered at the Central Hall, Westminster, before an audience of about 800 people by Commander J. C. Hunsaker, U.S.N. (C.C.), the subject being "Naval Architecture in Aeronautics." His Royal Highness the Duke of York honoured the Society with his presence in the Chair.

Meetings.

With the commencement of the 56th Session in October, 1920, it was decided to hold meetings in the afternoon in place of the evening as formerly, which has appeared on the whole to be a welcome innovation. The practice of certain other institutions, and an old practice of the Society, of having more than one paper read at some meetings was adopted, and also in most cases abstracts only were read. These experiments have, however, aroused some discussion and a reversion to the practice of having only one paper at each meeting has been decided upon. The full list of papers read since the last Report is as follows:—

1920.

April 14.—Subject, "Transcontinental Flying"; Lecturer, Capt. P. D. Acland; Chairman, Major-General E. D. Swinton, C.B., D.S.O.

April 28.—Subject, "Aerial Transport from a Business Point of View"; Lecturer, Major-General Sir Sefton Brancker, K.C.B.; Chairman, Major-General Sir F. H. Sykes, G.B.E., K.C.B.

May 12.—Subject, "Notes on Flying Boat Hulls"; Lecturer, Major Linton Hope, M.I.N.A.; Chairman, Prof. L. Bairstow, C.B.E., F.R.S.

May 26.—Subject, "Some Points of Importance in the Work of the Advisory Committee for Aeronautics"; Lecturer, Sir Richard Glazebrook, K.C.B., F.R.S.; Chairman, Major-General Sir E. L. Ellington, K.C.B., C.M.G., C.B.E.

56th Session.

October 7.—Subject, "Civil Aviation"; Lecturer, Major-General Sir F. H. Sykes, G.B.E., K.C.B.; Chairman, Rt. Hon. A. H. Illingworth, M.P.

October 21.—Subject, "Comparison of the Flying Qualities of Single and Twin-engined Aeroplanes"; Lecturer, Squadron Leader R. M. Hill, M.C., A.F.C.; Chairman, Major-General Sir Sefton Brancker, K.C.B.

,, Subject, "Night Flying"; Lecturer, Major Cecil Baker, D.F.C., A.F.C.

November 4.—Subject, "The Human Machine in Relation to Flying"; Lecturer, Wing Commander Flack, C.B.E.; Chairman, Sir Humphry Rolleston, K.C.B., F.R.C.P.

November 18.—Subject, "The Problem of the Helicopter"; Lecturer, Mons. Louis Damblanc; Chairman, Air Vice-Marshal Sir E. L. Ellington, K.C.B.

December 2.—Subject, "Airship Mooring"; Lecturer, Flight Lieut. F. L. C. Butcher.

,, Subject, "Airship Piloting"; Lecturer, Maj. G. H. Scott, C.B.E., A.F.C.; Chairman, Air Marshal Sir H. M. Trenchard, Bart., K.C.B.

December 16.—Subject, "Possible Developments in Aircraft Engines"; Lecturer, H. R. Ricardo, A.M.Inst.C.E., M.I.Aut.E.

,, Subject, "Installation of Aeroplane Engines"; Lecturer, A. J. Rowledge, A.M.I.Mech.E., M.I.Aut.E.; Chairman, Lieut.-Col. H. T. Tizard, A.F.C.

1921.

January 20.—Subject, "The Cost of Air-Ton Miles Compared with Other Forms of Transport"; Lecturer, Rt. Hon. Lord Montagu of Beaulieu, C.S.I., M.P.; Chairman, Rt. Hon. Lord Weir of Eastwood.

February 3.—Subject, "Ground Engineering"; Lecturer, Wing Commander H. W. S. Outram, C.B.E.

,, Subject, "Meteorology in the Service of Aviation"; Lecturer, Major Gordon Dobson; Chairman, Dr. G. C. Simpson, C.B.E., F.R.S.

February 17.—Subject, "The Handley Page Wing"; Lecturer, Mr. F. Handley Page, C.B.E.; Chairman, Sir Joseph Petavel, K.B.E., F.R.S.

March 3.—Subject, "Airship Fabrics"; Lecturer, Mr. J. W. W. Dyer.

,, Subject, "Parachutes"; Lecturer, Major T. Ord Lees, O.B.E., A.F.C.; Chairman, Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C.

March 17.—Subject, "Flying Boat Construction"; Lecturer, Capt. D. Nicolson.

JUVENILE LECTURE.

January 11.—Subject, "Airship Flights of Fact and Fancy"; Lecturer, Air Commodore E. M. Maitland, C.M.G., D.S.O., A.F.C.; Chairman, Lieut.-Col. W. Lockwood Marsh, O.B.E.

The Council beg to thank most cordially the gentlemen who kindly read the papers and also those who consented to act as Chairmen.

Annual Dinner.

The first Annual Dinner that has been held for many years took place at the Connaught Rooms on November 17th when Lord Weir, the President, occupied the Chair, and 137 members and guests were present. The dinner was, it is felt, an unqualified success, which it is hoped to repeat next year. It may be mentioned that it involved no expense to the Society, there being in fact a small balance on the credit side after all expenses had been paid, the President having very kindly made himself responsible for some of the expenses.

Visit to the National Physical Laboratory.

Through the kindness of the Director of the National Physical Laboratory, a visit to the Aerodynamics' Department was arranged on January 26th, when about 50 members availed themselves of the opportunity of being shown over the experimental apparatus installed. It is hoped to arrange for a series of similar outings during the coming year as they appear to be likely to prove a popular feature.

Applications for Membership.

The Council have approved a scheme of examinations, and special qualifications to be accepted in lieu thereof, for admission to Associate Fellowship, and the detailed regulations for this and certain modifications in the regulations for the admission of Fellows are being laid before members for their concurrence at the Annual General Meeting.

Revision of Rules.

It has been felt for some time that certain modifications and additions to the Rules are advisable, and the opportunity has been taken of making the alterations rendered necessary by the new regulations referred to above to revise carefully all the Rules. The amendments proposed by the Council will therefore also be laid before the Annual General Meeting. It should perhaps be mentioned that it was felt desirable to introduce as little alteration as possible consistent with what the Council have felt to be the revision necessary.

Finance.

The Council beg to report that the past year's working has resulted in a deficit of £481 3s. 4d. as shown in the Income and Expenditure Accounts for the two periods of six months ending June 30th and December 31st, 1920. When compared with the deficit on a similar basis of £1,780 for the previous twelve months, it is felt that this result may be received with a certain satisfaction. The improved position is due in part to the increase in subscriptions and also to a considerable extent to the exercise of economies in the production of the Journal and to the cutting down of other printing expenses to the minimum possible. The Council are glad to be able to report that should conditions remain unchanged there is every reason to hope that during the year 1921 the receipts should be sufficient to cover the expenditure, particularly if a new advertisement contract for the Journal, which has been entered into as from January 1st, 1921, proves as advantageous as appears likely. It must, however, be borne in mind that so far as the Balance Sheet is concerned, there is a deficit of £1,542 19s. 11d. which has to be carried forward and which there seems little hope of wiping off for some years to come in the ordinary course of events. It may be mentioned in conclusion that a more detailed system of book-keeping has been introduced during the year as a result of which the ascertaining of the precise state of the finances at any time is made a matter of greater ease and certainty than before. This system has the advantage of rendering it more easy to locate causes of expense and consequently may be trusted to lead to more efficient and economical working. It is hoped also to exercise certain economies in the methods of auditing during the current year.

Publications.

Efforts have been made during the year to increase the interest of the AERONAUTICAL JOURNAL by printing more original articles as well as by getting together the best possible programme of lectures. An endeavour has been made also to keep members more in touch with the work of the Society both by improving the announcements at the beginning of the Journal, and by circulating to the aeronautical and daily Press weekly notices, which cover as far as possible both information as to arrangements and activities and the various decisions arrived at by the Council.

Honorary Officials.

The Council desire to express their most cordial thanks to Mr. B. Woodward, whose advice as Honorary Solicitor has been called upon on several occasions during the year, and to Mr. A. E. Turner, the Honorary Treasurer, who has given invaluable assistance in dealing with financial matters.

Auditors.

The Council desire to express their appreciation of the way in which the new firm of auditors, Messrs. Price, Waterhouse and Company, have carried out the two six-monthly audits, and also of Mr. F. C. Best's assistance in the preliminary work of preparing the figures for the audit. It is proposed during this year to rely upon the assistance of Mr. Best only for the preparation of a statement of the financial position at the end of the first six months, having an official audit at the end of the year.

Staff.

The Council feel that members are to be congratulated upon the keenness and efficiency of the office staff employed. This now numbers four—Secretary, Assistant Secretary, Book-keeping Clerk (Miss G. B. Silvester), and Junior Clerk (Miss F. Barwood).

Your Council wish to express their thanks to the Secretary, Colonel Lockwood Marsh, for the able and thorough manner in which he has carried out his duties in the past 12 months. The great improvement in the financial position, as compared with last year, is largely due to his efforts, and he has conducted all the business of the Society with unfailing tact and energy.

Miss O. St. Barbe, the Assistant Secretary, has a knowledge of the Society's work which has been invaluable during the first year of service of a new Secretary, and shows undiminished zeal and resource in furthering its aims; while the two assistants have proved themselves exceptionally hard-working and efficient.

HON. TREASURER'S STATEMENT IN PRESENTING THE ACCOUNTS FOR THE HALF-YEAR ENDED 31st DECEMBER, 1920.

The Income and Expenditure Account for the second half of last year shows a net deficiency of £203 18s. 2d., which, added to the deficiency of £277 5s. 2d. for the previous six months, makes a total deficiency for the year of £481 3s. 4d., as against the anticipated deficit of £850. The difference is accounted for by the fact that receipts for the second half-year had been estimated to be the same as for the first half of the year, while, in fact, they were £100 higher. The estimated decrease of £100 in expenditure was almost exactly realised, and it was only found necessary to write off £150 on account of arrears of subscriptions instead of the estimate of £400.

For the current year it seems not unreasonable to anticipate that the Society's income should almost, if not quite, balance the expenditure. There seems reason to hope for a somewhat increased subscription income; and the new advertisement contract for the Journal is expected to produce a substantial increase on the amount hitherto received from this source.

The Finance Committee has always hesitated to suggest inviting donations for the purpose of wiping out the accumulated deficiency of nearly £1,600 until such time as the Society's current finances appeared to be on a satisfactory basis. This time would now seem to have arrived, and it is accordingly suggested that in issuing their report for last year, the Council invite donations to a fund for this purpose.

ARTHUR E. TURNER.

February 15th, 1921.

AERIAL
(The Royal

INCOME AND EXPENDITURE ACCOUNT FOR THE

Dr.	£	s.	d.
To Office Rental, Lighting and Insurance	161	8	5
,, Salaries	535	18	3
,, Printing, Stationery, etc.	131	17	1
,, Postages and Messengers	43	12	8
,, Library Expenses	10	0	5
,, Office Expenses	32	13	5
,, Exhibitions and General Meetings	93	19	7
,, Journals, Pamphlets, etc.	173	9	8
,, Audit Fee	26	5	0
,, Subscriptions Written-off or Refunded	28	4	0
,, Reserve against Subscriptions Outstanding	149	1	6
	£1,389	10	0

BALANCE SHEET

	£	s.	d.	£	s.	d.
To Nominal Capital—						
Divided into 20 Shares of 1/- each and 999 Shares of £1 each	1,000	0	0			
,, Capital Issued and Called Up—						
11 Shares of 1/- each					11	0
,, Sundry Creditors				438	4	10
,, Subscriptions Received in Advance				152	5	4
,, Reserve Fund—						
Entrance Fees and Life Compositions of present Members, as at 30th June, 1920	2,421	0	0			
Receipts for six months to 31st Dec., 1920...	123	18	0			
Donations received	30	10	0			
	2,575	8	0			
Less Payments	12	12	0			
	2,562	16	0			
Deduct, Income and Expenditure Account— Deficiency at 30th June, 1920 ... ... £1,339 1 9						
Add Excess of Expenditure over Income for six months to 31st December, 1920 ... 203 18 2						
	1,542	19	11			
				1,019	16	1
				£1,610	17	3

We report to the Shareholders that we have examined the books of the (We are not in a position to judge of the value put upon the outstanding sub properly drawn up so as to exhibit a true and correct view of the state of the given to us and as shown by the books of the Society.

3, Frederick's Place,
Old Jewry, E.C.2.
10th February, 1921.

SCIENCE, LTD.

Aeronautical Society).

SIX MONTHS ENDING 31st DECEMBER, 1920.

Cr.

	£	s.	d.
By Subscriptions Apportioned for the Six Months	1,070	11	0
,, Sundry Subscriptions	62	14	8
,, Interest on War Loan and Deposit	20	4	8
,, Profit on Annual Dinner	32	1	6
,, Balance, being excess of expenditure over income	203	18	2
	£1,389	10	0

31st DECEMBER, 1920.	£	s.	d.	£	s.	d.
By Office Furniture, Printed Books, Bindings, Stationery, Old Prints, etc., as at 30th June, 1920 ...				355	16	8
,, Stock of Journals, etc., in hands of Society and with Society's Printers, as estimated by the Secretary				50	0	0
,, Stock of Stationery				13	0	0
,, Sundry Debtors, including Subscriptions Owing ...				298	16	6
,, Investments at Cost—						
£500 5% War Loan (Inscribed Stock, 1929/47)	475	13	6			
£100 5% War Bond	100	0	0			
				575	13	6
,, Cash at Bank and on Deposit	316	10	2			
,, Cash in hand	1	0	5			
				317	10	7
				£1,610	17	3

Society and have obtained all the information and explanations we have required. scriptions.) Subject to this remark, we are of opinion that such Balance Sheet is Society's affairs according to the best of our information and the explanations

PRICE, WATERHOUSE & CO.

PROCEEDINGS.

SIXTH MEETING, 56th SESSION.

The Sixth Meeting of the Fifty-Sixth Session was held in the Hall of the Royal Society of Arts, London, on Thursday, December 16th, 1920, Lieut.-Col. H. T. Tizard presiding.

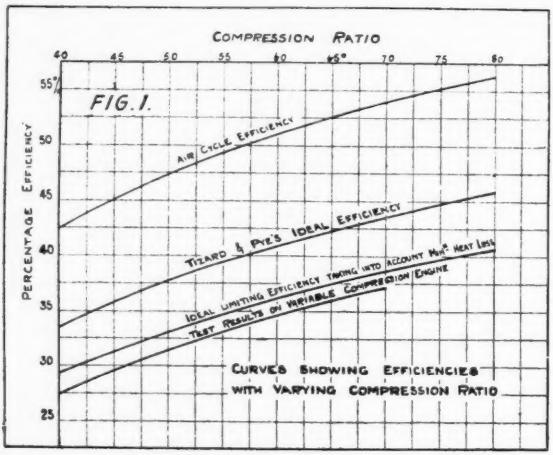
The CHAIRMAN said the Lecturers, Mr. Ricardo and Mr. Rowledge, were so well known to the members that it would be a waste of time to enumerate their virtues. He would ask Mr. Ricardo to read his Paper.

Mr. H. R. RICARDO then delivered the following lecture:—

SOME POSSIBLE LINES OF DEVELOPMENT IN AIRCRAFT ENGINES.

In the following paper the writer's aim is to indicate certain possible lines of development and research which his own investigations and preliminary experiments have shown to be at least worthy of serious consideration.

If we review the present state of the art we find the position to be substantially as follows:—From a thermodynamic point of view the performance of the modern aero engine has approached so nearly to the ideal obtainable from the cycle on which it operates that there is little scope for improvement. Thermal efficiency or fuel consumption is now the all-important factor, but since the best modern aero engines are actually developing a thermal efficiency within 4 or 5 per cent. of the highest obtainable from the cycle on which they operate, it is evident that



to gain any further improvement it will be necessary either to depart from, or at least to take considerable liberties with, the accepted cycle, or to modify the composition of the fuel, or both.

The cycle on which all present-day aero engines operate is one in which an explosive mixture of fuel and air is drawn into the cylinder compressed to the highest pressure permissible without detonation and ultimate pre-ignition, then ignited at constant volume and expanded until it occupies the same volume as before compression, after which it is released and the cycle is repeated. The theoretical efficiency of this cycle is given by the formula $E = 1 - (1/r)^{\gamma - 1}$

This is known as the air standard efficiency; it assumes that the specific heat is constant at all temperatures, that there is no loss of heat and that there is no dissociation. According to this formula the efficiency is dependent upon r, the

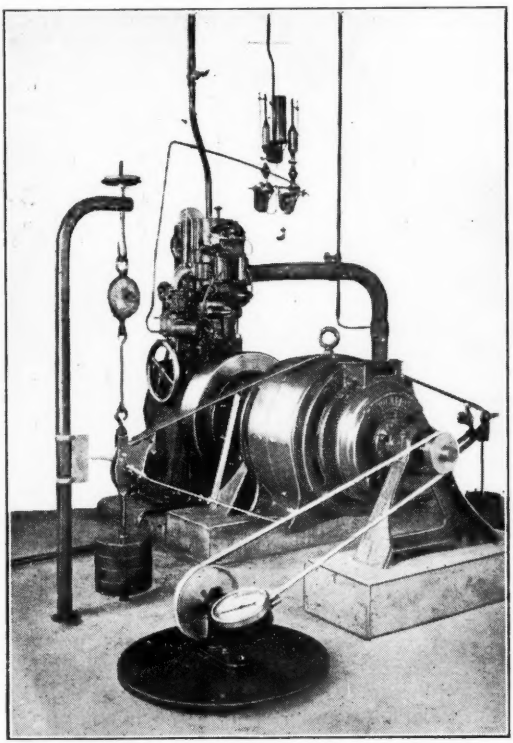


FIG. 2.

expansion ratio. In the ordinary cycle r is also the compression ratio, since compression and expansion happen to be equal, but it must be remembered that it is the expansion and not the compression ratio which governs the efficiency, and that the two need not necessarily be equal.

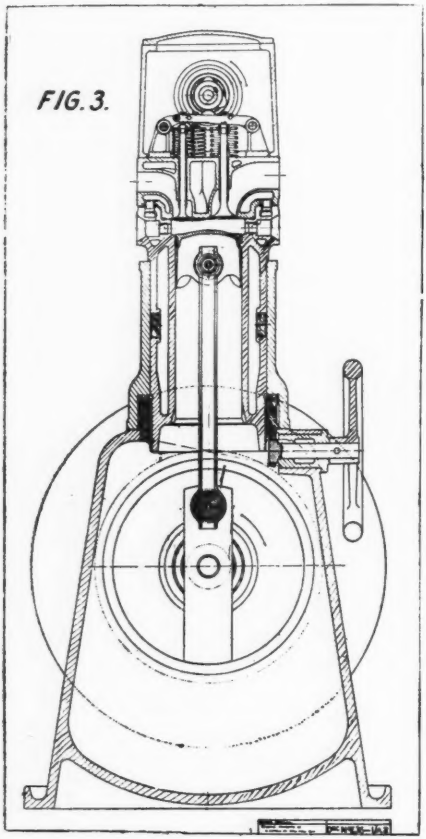
The most recent investigations on the properties of the working fluid carried out by Mr. Tizard and Mr. Pye and corroborated by the writer's experimental results, show that when due allowance has been made for the losses due to change of specific heat and to dissociation at the temperatures which actually obtain in the cylinder, the true limiting thermal efficiency becomes approximately $E = 1 - (1/r)^{0.295}$. This formula takes no account of the losses due to the direct passage of heat to the cylinder walls during combustion and expansion. It is

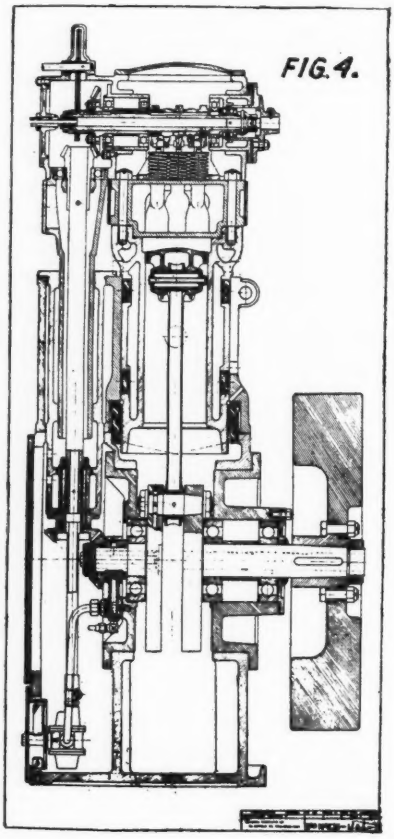
clearly impossible to arrive at a really universal formula which will take this into account, since the proportion of heat lost must depend upon the form of the combustion chamber, the speed, and, in fact, on the individuality of each engine. In the most perfect case of an engine having a compact and symmetrical combustion chamber and running at a high speed, so that the direct heat loss during combustion and expansion is reduced to the absolute minimum, the highest attainable indicated thermal efficiency is given pretty accurately by the formula $E = 1 - (1/r)^{0.25}$. This allows for the minimum possible heat loss to the jacket walls and may be regarded as the absolute limiting thermal efficiency obtainable under the best possible conditions, assuming :—

(1) Perfect carburation and distribution.

(2) That the compression and expansion ratios are equal.

(3) That the mixture is homogeneous and of the most economical strength.





The following table (Table I.) and the curves shown in Fig. 1 gives in column (1) the air-cycle efficiency for a range of compression ratios from 4 : 1 to 8 : 1 column (2), Tizard and Pye's ideal efficiency, taking into account losses due to change in specific heat at high temperatures and to dissociation, column (3) the highest attainable indicated thermal efficiency assuming that the combustion

chamber is designed to allow of the minimum possible heat loss, that the cylinder is of comparatively large capacity and that the revolutions are not less than 1,500 r.p.m. In column (4) are given the actual indicated thermal efficiencies as obtained in a special variable compression engine designed by the writer for research purposes, and in which every known artifice for obtaining the highest possible efficiency and power output has been employed. A photograph and sectional drawings of this engine are shown in Figs. 2, 3 and 4.

TABLE I.

Expansion ratio.	Col. 1. $E = 1 - (1/r)^{0.4}$	Col. 2. $E = 1 - (1/r)^{0.295}$	Col. 3. $E = 1 - (1/r)^{0.25}$	Col. 4. Observed results variable compression engine.
4.0	0.4256	0.336	0.296	0.277
4.5	0.4521	0.359	0.314	0.297
5.0	0.4747	0.378	0.332	0.316
5.5	0.4944	0.396	0.348	0.332
6.0	0.5116	0.411	0.361	0.346
6.5	0.5270	0.424	0.375	0.360
7.0	0.5398	0.437	0.386	0.372
7.5	0.5534	0.449	0.396	0.383
8.0	0.5647	0.460	0.406	—

The difference between columns 3 and 4 indicates the scope left for improvement—it is very narrow.

So long as the recognised cycle is adhered to, in its entirety, the importance of raising the compression and therefore the expansion is obvious. Now when working with all fuels belonging to the general group known as petrol the compression pressure which can be employed is limited by the tendency of the fuel to detonate and ultimately to pre-ignite.

The explanation of the phenomena of detonation appears to be as follows:—

When the mixture is ignited from any one point, the flame at first spreads by the normal process of flame propagation aided by turbulence and in doing so compresses before it the unburnt portion of the charge; unless this latter can get rid of its heat with sufficient rapidity, it is liable to be compressed to a temperature exceeding its self-ignition temperature, with the result that it ignites spontaneously throughout its whole bulk and an explosion wave is set up which strikes the walls of the cylinder with a hammer-like blow, giving rise to the familiar noise known as "pinking." This explosion wave further compresses the portion of the charge first ignited, thus still further raising its temperature, and with it the temperature of the igniter points or any other partially insulated object in the neighbourhood from which ignition first started, to so high a temperature as ultimately to cause pre-ignition and loss of power. Pre-ignition, which is the ultimate limiting factor controlling the compression, never occurs under normal conditions with petrol, except as a result of persistent detonation. If detonation be prevented, a much higher compression can at once be used without any risk of pre-ignition, and a very decided gain both in power and efficiency obtained thereby.

There can be little doubt but that detonation depends primarily upon the normal rate of burning of the fuel, and this in turn depends upon the pressure, and, to a less extent, upon the temperature at the time of ignition. If means be adopted either for slowing down the normal rate of burning or raising the self-ignition temperature of the fuel, or both, detonation can be kept in control and a much higher compression ratio can be used. Either or both of these methods are available. With the exception of ether, acetylene and hydrogen, fuels composed of light paraffin fractions have been proved to be the worst offenders as regards detonation—they are chain compounds and therefore chemically unstable, their ignition point is low, and their normal rate of burning very rapid. On the other

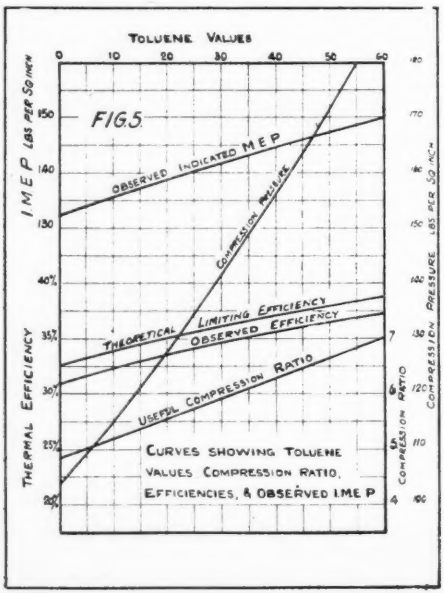
hand, fuels belonging to the aromatic group, such as benzene, toluene and xylene are ring compounds of greater chemical stability and high ignition temperature, they cannot be made to detonate even with compression ratios as high as 7.5 : 1.

It has been known for a long time that by adding benzol or benzene to paraffin petrols the tendency to detonate could be greatly reduced, but recent experiments at the writer's laboratory have shown that of these three members of the aromatic group, benzene is the least effective and toluene the most, while xylene occupies a position midway between the two. On account of their relatively low heat value per lb. it is naturally desirable to employ as small a proportion of aromatics as possible. Of the three aromatics mentioned, benzol has also the highest specific gravity and the lowest heat value per lb. It is therefore from every point of view the least efficient of the three.

Experiments on the variable compression engine have shown that the compression pressure can be raised in direct proportion to the aromatic content of the fuel. A light petrol freed from aromatics and consisting mainly of fractions of the paraffin series, but conforming in every respect to the Air Ministry's specification for aircraft spirit, detonates under normal conditions as to temperature, etc., and with the most efficient mixture strength and ignition timing at a compression ratio of 4.85 : 1 (the degree of compression at which detonation starts being very sharply defined). By adding 20 per cent. of toluene the compression can be raised from 4.85 : 1 to 5.57 : 1, the gain in efficiency on actual test is found to be from 31.1 per cent. to 33.5 per cent., and in mean effective pressure from 131.8lbs. per sq. inch to 140lbs. per sq. inch. Now the addition of 20 per cent. toluene adds less than 2 per cent. to the weight of the fuel per unit of heat and permits of an increase in efficiency of 7 per cent. The net gain is therefore very considerable.

Finding toluene the most efficient medium for preventing detonation, it was decided to express the tendency of fuels to detonate in terms of their toluene value.

Starting with a light paraffin petrol, freed from aromatics, the relation between toluene value and the highest compression ratio which could usefully be employed was found to be as shown in the following table and the curves in Fig. 5 :—



Toluene value.	Compression ratio.	Ind. mean pressure as found by experiment.	Ind. thermal efficiency as found by experiment.	Limiting Ind. thermal efficiency.
0	4.85 : 1	132.5	.311	.327
10	5.20 : 1	135.4	.323	.338
20	5.57 : 1	138.7	.335	.350
30	5.94 : 1	142.0	.347	.361
40	6.32 : 1	144.9	.355	.371
50	6.67 : 1	147.5	.365	.380
60	7.05 : 1	150.0	.373	.388

Later investigations showed that toluene was not the most efficient dope, and that, in fact, it could not compare with alcohol, though this fuel is not likely to be of much value for aircraft on account of its low heat value per lb.

The following table gives the toluene values of a number of different fuels. For permission to publish this table the writer is indebted to The Asiatic Petroleum Co., Ltd., for whom these and other investigations were carried out.

TOLUENE VALUE.

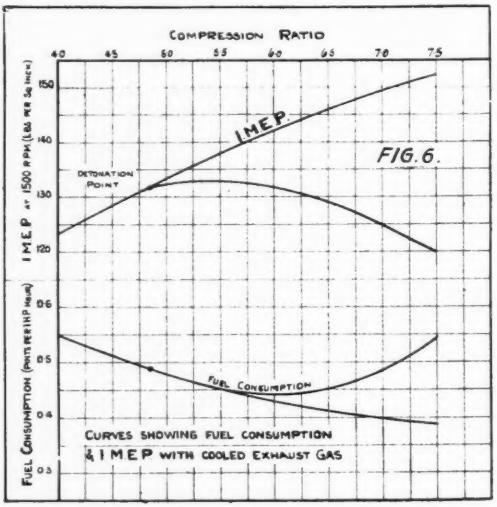
Toluene	+	100
Benzene	+	66
Xylene	+	83
Ethyl-Alcohol, 99 per cent.	+	166
Acetone	+	75
Cyclohexane	+	30
Carbon Bisulphide	+	10
Methyl Mercaptan	+	5 to 10
Ether	—	60

From this table it will be seen that the fuel known as hectar and consisting of 50 per cent. benzene and 50 per cent. cyclohexane, which the Americans have found so successful, therefore has a toluene value of 48, and could be used with a compression ratio of 6.6 : 1.

Before proceeding further it would be well to emphasise that of all the known volatile hydro-carbon fuels the total internal energy (taking into account the heat of combustion on the one hand and the change in specific volume on the other) is substantially the same, that is to say, when completely evaporated and used at the same compression ratio, all fuels, irrespective of their heating value, will give the same thermal efficiency and the same power to within about 2 per cent. The only exception is alcohol and the other members of its group; these, under normal conditions, give a slightly higher power because the increase of specific volume after combustion is very considerable, and also in practice owing to their higher latent heat they are seldom completely evaporated, with the result that a considerable amount of evaporation takes place in the cylinder during the suction stroke, thus both increasing the weight of charge and reducing the compression temperature.

Popular theories that benzol or mixtures of benzol and petrol give higher power at the same compression than pure petrol, owe their origin to the fact that most engines have already too high a compression for efficient use with pure petrol, with the result that a late ignition setting and often an over-rich mixture also must be used. The addition of benzol in such a case permits of the use of full ignition advance and the most efficient mixture strength, and so gives rise to this very prevalent impression. Actually the total internal energy of, and therefore the power output available from benzol, is very slightly less than petrol.

Apart from varying the composition of the fuel, which is not always practicable, a somewhat similar increase in compression and therefore in efficiency can be obtained by the addition of inert gases which serve merely to delay the normal rate of burning. Experiments with pure aromatic-free petrol of toluene value o showed that the safe compression ratio could be raised from 4.85 to 1 up to 7.5 : 1 by the addition of cooled exhaust gas. Fig. 6 shows the relation between mean

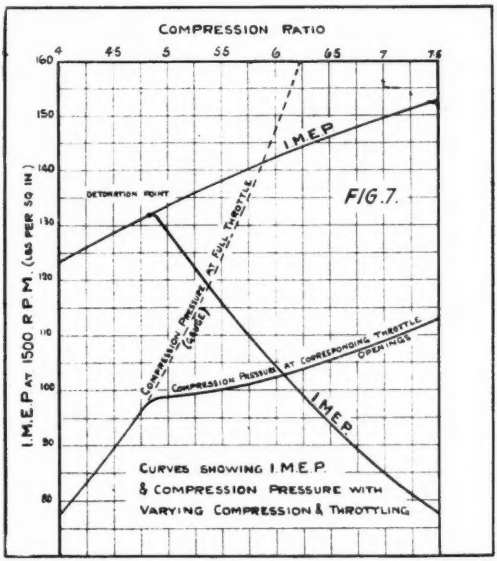


pressure, thermal efficiency and compression ratio, when just sufficient exhaust gas was admitted in each case to check detonation. In dotted lines are shown, by way of comparison, the mean effective pressure and efficiency obtained with a fuel of high toluene value and of the same total internal energy. The divergence between the two mean pressure curves indicates approximately the proportion of inert gas added. It will be observed that the compression ratio can be raised at once from 4.85 : 1 to over 6 : 1 without any reduction in power whatever, and with a very substantial gain in efficiency, thus it is possible to improve the economy of an engine by as much as 6 per cent. without affecting its horse-power one way or the other, by the mere addition of exhaust gas, costing nothing, and adding nothing to the weight of the engine.

To appreciate the possibilities of the use of exhaust gas in this manner, let us suppose that we have a fuel of toluene value o. With such a fuel the highest compression ratio we can use if the engine is to be capable of running "full out" at ground level, and with an economical setting, is only 4.85 : 1, corresponding to a limiting thermal efficiency of 32.7 per cent. By the addition of cooled exhaust gas a compression ratio of say 7 : 1 giving a limiting thermal efficiency of 38.6 per cent. could be used and still permit of the engine being run full out on the ground with perfect safety, and developing even at ground level very nearly the same power as the lower compression engine.

As the machine ascended the quantity of exhaust gas would be reduced until at about 12,000 feet it could be cut off altogether. It will be seen that, in this manner, not only can a high compression engine be made to operate safely on the ground with any fuel, but that the control of exhaust gas can be made to afford a very efficient altitude compensator.

By way of comparison, tests were run with varying compressions and with a fuel of toluene value o in order to ascertain the relation between mean pressure, compression pressure and compression ratio when detonation is prevented by throttling. The results obtained are shown in Fig. 7 and require no particular



explanation. It is interesting to note, however, that detonation became apparent at very nearly the same compression pressure in all cases. By way of comparison it will be noted that with this fuel the throttled engine with 7 : 1 compression ratio can develop only 57 per cent. of its full power on the ground while the exhaust controlled engine can develop 84 per cent.

Safety Fuels.

A good deal of interest has been shown lately in the question of employing fuels of high flashpoint to avoid fire risks. So far as the writer is aware, kerosene only has as yet been seriously considered. There are two possible methods of dealing with this fuel, (1) by vaporising it and so using it in a normal type of engine, (2) by injecting it into the cylinder as a liquid, either during the suction stroke or at the end of compression.

With regard to the first method, commercial kerosene consists almost entirely of heavy fractions of the paraffin series. These are all chain compounds, and their chemical stability decreases with increase in molecular weight. From the point of view of detonation, therefore, kerosene is one of the most troublesome fuels in existence. Further, in order to vaporise a reasonable proportion of it, it is necessary to raise its initial temperature to certainly not less than 60°C. This means a reduction in the weight of charge of at least 20 per cent. as compared with petrol, and a corresponding reduction in mean pressure. Further, owing to its chemical instability on the one hand and the high compression temperature resulting from pre-heating, the limiting compression is reduced to about 4.2 : 1 corresponding to a limiting thermal efficiency of only 30.2 per cent. and a limiting indicated mean pressure of only about 115lbs. per sq. inch or say 100lbs. per sq. inch brake mean pressure. Again, no means have yet been discovered of preventing the heavier fractions condensing on the cylinder walls and passing down

into the crank-case, where they soon prove destructive to the bearings, etc. So serious has this trouble proved in the case of stationary kerosene engines that so far the only kerosene engines of normal type which have given consistently satisfactory results over long periods are those in which the working parts are open and each bearing is lubricated individually. Although detonation can be kept in check and a comparatively high compression ratio employed with the help of the addition of exhaust gas, yet the low-power output, the condensation trouble, and the low efficiency are such serious drawbacks as, in the writer's opinion, to put kerosene out of court as a fuel for existing types of aero-engines. The alternative method of injecting the fuel is not much more hopeful so long as it is applied to the existing type of engine. If the fuel is injected on the suction stroke one avoids the loss due to pre-heating, and can therefore use a higher compression and obtain considerably higher power, but the condensation trouble becomes more serious than ever, while the problem of measuring and pumping small quantities of fuel and maintaining correct proportions between the fuel and air at all loads and speeds is no easy one.

Lastly, if the fuel be admitted at the end of compression and ignited on entry by means of a hot plate or other igniter, the very formidable difficulty of so pulverising and distributing the fuel that each particle can find at once the necessary air for complete combustion has got to be tackled; it is one which is very familiar to the Author from bitter experience with Diesel and semi-Diesel engines.

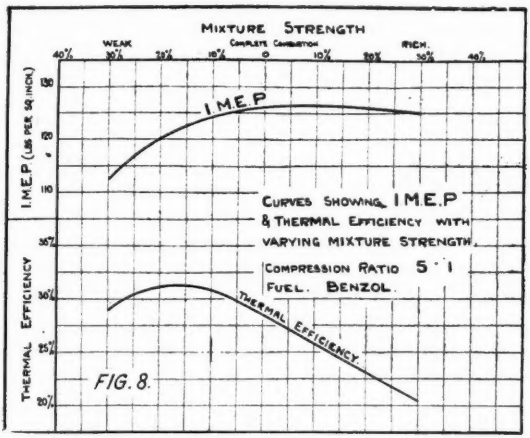
There is, however, another way of dealing with the high flashpoint fuel problem which, in the writer's opinion, is the most hopeful at the moment. Many natural kerosenes contain a considerable proportion of heavy aromatic hydrocarbons having the same characteristics as regards flashpoint as the kerosene of which they form a part. These aromatics burn with a smoky flame, and are therefore very objectionable when the fuel is used as an illuminant. Recently steps have been taken to isolate and remove these heavy aromatics, and at the present time they are being removed at the rate of several thousand tons per month. Their use as a safety fuel for aircraft engines is worthy of careful consideration. Owing to their almost complete immunity from detonation they can be used with a very high compression ratio, even after pre-heating in a vaporiser. Experiments made with these aromatic extracts show that with an inlet temperature of 60°C. it is still possible to use a compression ratio as high as 6 : 1, and even 6.5 : 1. with the result that the efficiency is very high and the power output equal to or very nearly equal to that obtained with ordinary petrol of low Toluene value. Direct comparative tests carried out with paraffin and samples of these aromatic extracts gave the following results:—Kerosene sp. gr., 0.812; I.M.E.P., 111.0; Fuel pt. per 1 H.P. hr., 0.595; Aromatic Extracts sp. gr., 0.884; I.M.E.P., 125.5; Fuel pt. per 1 H.P. hr., 0.42. In both cases exactly the same vaporiser temperature was used, the only difference being in the compression ratio employed. The results obtained are, in the writer's opinion, sufficiently encouraging to justify further investigation. The difficulty of condensation still remains, but this appears to be less serious than with kerosene since the freedom from any tendency to detonate permits of more pre-heating, while it is open to question whether the heavy aromatic condensate is as destructive to lubrication as the paraffin.

Influence of Mixture Strength.

In the earlier part of this Paper the writer has shown that because of the losses to dissociation, change of specific heat and direct heat losses, the limiting efficiency obtainable under the best conceivable conditions is only about 70 per cent. of the air cycle. Now each of these sources of loss is a direct function of the maximum temperature, which in turn is dependent upon the mixture strength. When the mixture is so proportioned that the whole of the available oxygen is just combined, the maximum temperature rises to approximately 2,500°C., and the

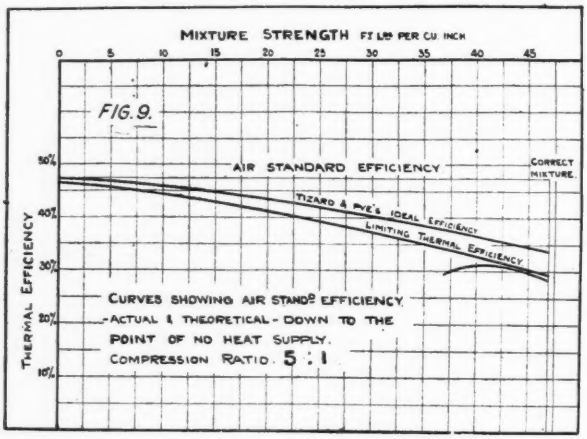
mixture strength is then approximately 47 ft. lbs. per cub. inch. As the mixture is weakened the maximum temperature is of course reduced, at first only very slightly, but so long as a homogeneous mixture is employed it is not possible to reduce the mixture to below about 40 ft. lbs. per cub. inch. without serious loss of efficiency due to incomplete combustion, owing to the limited range of burning of all volatile hydrocarbon fuels. The writer has carried out on behalf of the Asiatic Petroleum Company, Limited, a very large number of tests on about 40 different fuels in order to ascertain the relation between mixture strength, power and economy. Except for insignificant variations, the characteristic efficiency and power obtained by gradually weakening the mixture is the same for all fuels and at all compressions, excepting alcohol, which on account of its greater latent heat and its large increase in specific volume gives increasing power as the mixture is enriched for a long period after the point of complete combustion has been passed.

The curve (Fig. 8) shows the relation between thermal efficiency and mixture

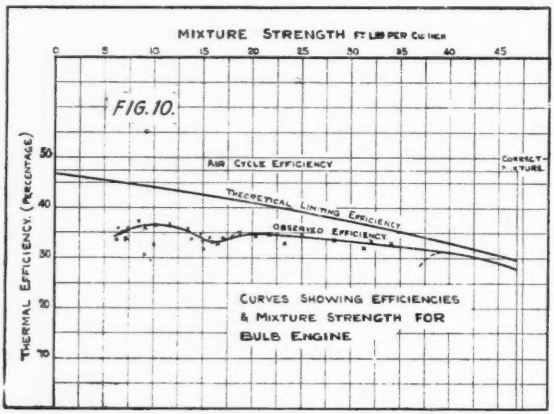


strength expressed in terms of mean pressure. The example shown is taken with benzol at a compression ratio of 6 : 1 and, with but infinitesimal variations, it may be taken as applying to any fuel except alcohol. It will be observed that maximum efficiency is obtained when the mixture strength is such that the mean effective pressure is about 3 per cent. below the maximum. Any further weakening of the mixture results merely in loss of efficiency due to incomplete combustion. Now were it possible to control the power output by mixture strength alone, and still obtain complete combustion, it is clear that the maximum temperature would then be proportional to the load and would diminish as the load is reduced. As the temperature diminished so also would the losses due to dissociation, change of specific heat, and direct heat loss diminish until, at the point of no load and therefore of no heat supply, they would disappear entirely and the limiting efficiency would be virtually coincident with the air cycle. The accompanying curve (Fig. 9) shows how, under these conditions, the limiting thermal efficiency would vary with the load. In this diagram the horizontal line denotes the air-cycle efficiency which, since it takes no account of heat losses, etc., is constant for all loads, the sloping line denotes the theoretical limiting efficiency over the range from no load to full load, the third line represents the limiting efficiency with minimum heat losses, and the fourth the actual test results obtained over the range of mixture strength available with a homogeneous charge. While it is not possible to weaken the mixture strength so long as the charge is homogeneous, it is possible to do so

by means of stratification, that is to say, by supplying the cylinder with a relatively small charge of combustible mixture and admitting separately a large charge of air, keeping the two separate until after ignition. To do this it is necessary to reconcile two conflicting conditions—the two portions of the charge must be prevented from mixing till after ignition, and at the same time there must be


MIXTURE STRENGTH FT LBS PER CU INCH
0 5 10 15 20 25 30 35 40 45
FIG. 9.
AIR STANDARD EFFICIENCY
CORRECT MIXTURE.
TIZARD & PYE'S IDEAL EFFICIENCY
LIMITING THERMAL EFFICIENCY
THERMAL EFFICIENCY
50% 40% 30% 20% 10%
CURVES SHOWING AIR STAND^D EFFICIENCY -ACTUAL & THEORETICAL- DOWN TO THE POINT OF NO HEAT SUPPLY.
COMPRESSION RATIO 5 : 1

sufficient turbulence in the combustible charge to ensure rapid combustion. These two conditions are not irreconcilable, and the writer has succeeded experimentally on two engines in obtaining the whole range from dead light to full load by controlling the fuel alone. Under these circumstances not only is the efficiency on reduced loads far higher than could be obtained by any other means, but the heat loss is so low that a water-cooled engine can be run at reduced loads for any length of time without cooling water.

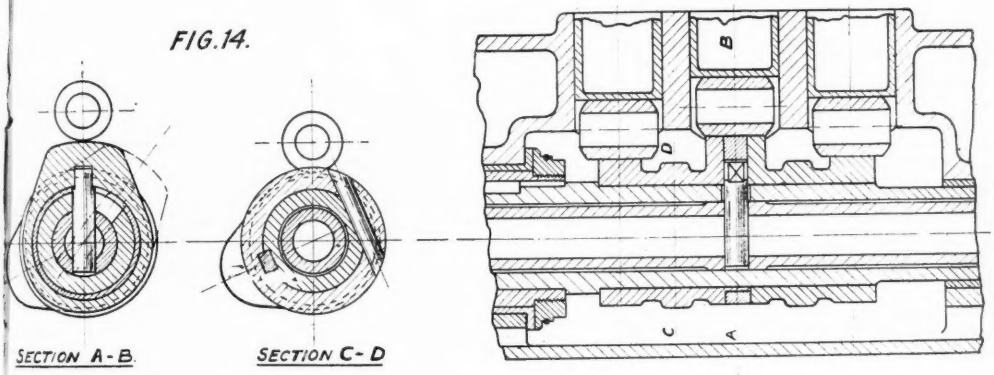

MIXTURE STRENGTH FT LBS PER CU INCH
0 5 10 15 20 25 30 35 40 45
FIG. 10.
AIR CYCLE EFFICIENCY
THEORETICAL LIMITING EFFICIENCY
OBSERVED EFFICIENCY
THERMAL EFFICIENCY (PERCENTAGE)
50 40 30 20 10
CURVES SHOWING EFFICIENCIES & MIXTURE STRENGTH FOR BULB ENGINE

The accompanying curve (Fig. 10) shows the efficiency actually obtained in one experimental engine with a compression ratio of only 5 : 1. It will be observed that it rises to no less than 37 per cent. at about one third full load corresponding to a fuel consumption of just under 0.36 pint of benzol per indicated horse-power hour. It will be seen that the curve of efficiency actually obtained follows the

theoretical curve with a reasonable degree of approximation. In Figs. 11-14 are shown some typical indicator diagrams taken from one of the two engines with a Hopkinson optical indicator. It should be noted that when working on this system distribution troubles disappear. In any ordinary multi-cylinder engine it is necessary so to proportion the mixture that the weakest cylinder receives a charge of a

certain minimum strength to ensure regular running; this means that other cylinders are receiving a slightly richer charge than is absolutely necessary and their efficiency is therefore reduced. On the other hand, when working with a stratified charge, the power output of each cylinder is dependent solely upon the quantity of fuel admitted to it, so that any cylinder which receives a richer mixture than others will develop correspondingly more power, and the economy will always be at a maximum, that is assuming, of course, that the mixture strength is at all times below that required to consume the whole of the oxygen. Again, from the point of view of altitude compensation nothing could be simpler, for (so long as the oxygen in the cylinder is not all consumed) constant power can be maintained

FIG. 14.



SECTIONS THROUGH CAM BLOCK

over any reasonable range of density by merely supplying a constant fuel feed, *e.g.*, by gravity, or if a carburettor is used in its crudest form, the variation in power with altitude will correspond with the natural characteristic of the carburettor and will therefore vary as the square root of the density.

With a view to gaining further practical experience with this system, one of the two gas engines supplying power to the writer's laboratory was, about nine months ago, converted to run with stratified charge and control on the fuel alone. Since that date it has run continuously under violently fluctuating loads and has developed no trouble of any kind. It is running in parallel with another engine identical in every respect but working on the ordinary cycle. In the case of the latter engine it is necessary to remove the cylinder head every two months for decarbonising and grinding in the exhaust valve, while the cylinder of the engine working on the stratified charge has only been opened once, when it was found to be practically clean, while the exhaust valve appeared to keep almost as cool as the

inlet valve in the other engine. As regards governing and regularity of running there is nothing to choose between the two engines, each of which can develop a maximum of 24 b.h.p. at 750 r.p.m.

Although the above experiments suggest that the system has been developed to a practical stage, the writer feels that this is hardly yet the case and that considerably more research is required before it can be considered wholly satisfactory.

In the writer's opinion the potentialities of working with a stratified charge cannot be over-estimated. It opens up the possibility of obtaining far higher efficiencies than are obtainable by any other known means, and what is perhaps equally important, it reduces the temperature of the cycle and with it all the troubles due to high temperatures which directly or indirectly are the root cause of most mechanical failures. Since the rate of heat flow to the cylinder walls varies roughly as the cube of the temperature, and the power output practically directly as the temperature, it follows that quite a small reduction in power will reduce the heat losses to an extent that must render air-cooling quite a simple problem.

The possibilities of working with a short compression and long expansion stroke deserve careful consideration. In effect this can be accomplished by the simple expedient of closing the inlet valve late, so that compression does not start until well up the compression stroke; this method has both direct and indirect advantages. The direct advantages are that while the compression pressure is controlled by the nature of the fuel, the expansion ratio can be extended to any degree and very high efficiencies can be obtained, though, of course, at the expense of the power developed per unit of cylinder volume.

For example, suppose that a fuel of Toluene value O is used, then while the compression ratio is limited to 4.85 : 1 on the ground, the expansion ratio may be say 8 : 1. The limiting efficiency for 4.85 : 1 expansion is 32.7 per cent., and for 8 : 1, 40.6 per cent. The power output under these conditions will therefore be $4.85/8 = 60$ per cent. of that obtainable with an 8 : 1 compression, assuming that such a compression could be employed, or 73 per cent. of that obtainable if both compression and expansion ratio were 4.85 : 1. By varying the time of closing of the inlet valve the compression could be increased as the machine ascended, until at about 15,000 feet the full compression could be used and full power developed; thus the indicated thermal efficiency could be maintained at a maximum, and the power nearly constant over this range of altitude.

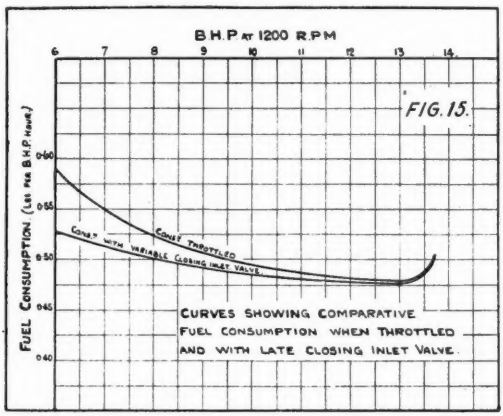
The indirect advantages are :—

(1) That with such a valve setting the engine has a rising torque curve which is a desirable characteristic.

(2) In the event of one cylinder dropping out and the speed falling in consequence, the compression in the remaining cylinders is reduced, and the shocks due to the irregular turning moment are also reduced. When controlled by throttling, the reverse is the case; if one cylinder drops out the others, owing to the drop in speed, take in a heavier charge, resulting in severe shocks and increased liability to detonation and pre-ignition.

(3) When working with a late closing inlet valve the whole charge enters the cylinder and a portion is rejected. The rejected portion, which returns to the manifold, has picked up a considerable amount of heat from the inlet valves, cylinder walls and residual exhaust gases, some of which heat it imparts to the inlet manifold with the result that, as the load is reduced, so is the temperature of the manifold increased, which is a desirable characteristic.

Some years ago the writer carried out a series of experiments with a patent variable inlet cam (shown in Fig. 15) fitted to a small experimental engine having an expansion ratio of 5.95 : 1. A number of very careful comparative power and consumption tests were made, the power output of the engine being controlled in the one case by varying the time of closing of the inlet valve, and in the other by using a normal valve setting and throttling the charge. The results obtained in



these experiments are shown in Fig. 16, from which it will be observed that the gain in efficiency in the former case, though perhaps not so large, is none the less quite appreciable. It should be noted that in these experiments the same expansion ratio was used in both cases, so that the advantage due to prolonged expansion was not obtained, and the gain in economy recorded is that due to indirect advantages alone.

In aircraft engines when one is working over a large range of atmospheric density the question always arises—at what density the engine shall be designed to give its best performance or at least to develop its full power. Until comparatively recently all engines were so designed that they could develop their full power

FIG. 16.

FIG. 17.

at ground level, without pre-ignition, without overheating, and without overstressing the parts. During the war, however, it became evident that this was unnecessary and undesirable, and manufacturers were urged to design their engines on the assumption that they would not be opened full out below 10,000 feet. So far as the writer is aware, no manufacturers actually produced such an engine. It is, however, interesting to consider what might be done in this direction. We will begin with the assumption that modern aviation spirit has a Toluene value of 10, which is about the average value of American aviation spirit. At 10,000 feet the air density is 0.72, and at this density a compression ratio of 7.0 : 1 could be used with such a fuel, giving a theoretical limiting thermal efficiency of 38.6 per cent. and a theoretical limiting mean pressure of approximately 165 lbs. per sq. inch reckoned at ground level or 119 lbs. per sq. inch at 10,000 feet. Under these conditions let us now consider what power the engine could develop at ground level, keeping just free from detonation. If controlled by throttling the maximum indicated mean pressure would be approximately 95lbs. per sq. inch. If controlled

by varying the time of closing of the inlet valve it would be considerably higher, because for various reasons the efficiency obtainable under these conditions is greater and would be very nearly in the ratio of 5.25 : 7.0 × 165 (5.25 being the limiting ground level compression ratio for a fuel of Toluene value 10) or say about 122lbs. per sq. inch. If controlled by the addition of cooled exhaust gas the mean effective pressure, as shown previously, would be very nearly equal to the full available M.E.P. with a compression ratio of 5.25 : 1 or 140 lbs. per sq. inch.

In all cases let us assume that the mechanical losses of the engine are equivalent to an M.E.P. of 15lbs. (a fair average figure). Then the theoretical limiting brake mean pressure in the three cases would be :—

(1) 80lbs. per sq. inch.
(2) 107lbs. per sq. inch.
(3) 125lbs. per sq. inch, while at 10,000 *feet the brake M.E.P. will be* 104*lbs. in all cases.*

In all three cases the explosion pressure would be substantially the same, and little or no higher than at 10,000 feet—that is about 450-500lbs. per sq. inch. In the latter case it will probably be actually lower, because the principal effect of the exhaust gas is to slow down the rate of burning and so round off the peak of the diagram.

Assuming that the propeller torque varies as the square of the speed and directly as the density, then, if the engine is designed to run all out at 10,000 feet at 1,500 r.p.m., its maximum speeds at ground level will be approximately 1,100, 1,270 and 1,320 r.p.m. respectively. In the former case such an engine would probably fail to leave the ground.

From these considerations it seems clear that the principle of designing a very high compression engine for use at high altitudes and throttling it on or near the ground is not the right one. Of the three methods considered, the use of exhaust products appears to be the most hopeful as a means of permitting a very high compression engine to operate satisfactorily at low altitudes, and still have sufficient power to get rapidly off the ground.

The alternative method of dealing with the problem of varying atmospheric pressure is to maintain artificially ground level density in the cylinder at high altitudes by supercharging. From the point of view of engine weight there can be no doubt that this method scores heavily, for, although the strength and weight of many of the parts may be proportional to the density in the cylinder, there still remains a very considerable number whose weight is altogether independent of the pressure in the cylinder, so that the weight of the engine, as a whole, can only vary as the density plus a very large constant.

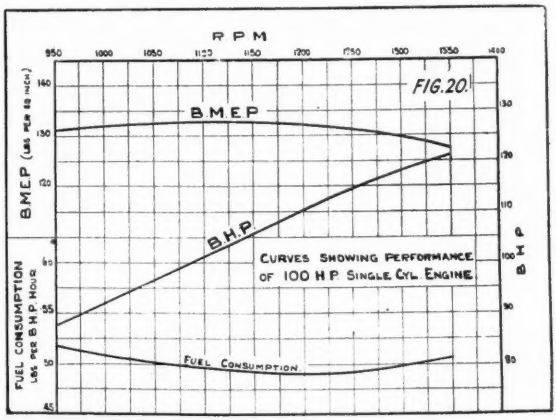
There are at least two possible ways of dealing with the supercharging problem, one by merely forcing more fuel and air into the cylinder by means of a pump or blower and the other by employing a supercharge of pure air in a stratified form.

Some four years ago the writer carried out a very extensive series of tests on this latter system, and obtained most encouraging results on two experimental engines, but had to break off these experiments and concentrate all his attention on engines for tanks. The results obtained were, however, so encouraging that further tests should be made. Apart from the obvious increase in power at high altitudes this system of supercharging provides a perfect and automatic compensation of mixture strength for altitude, and gives a considerable increase in economy, the consumption falling from 0.49lbs. per b.h.p. hour when running normally to 0.455lbs. when supercharging.

Limiting Size of Cylinder.

Designers of aircraft engines have, in the writer's opinion, shown quite unnecessary timidity in regard to the power output obtainable from individual

cylinders. So far as the writer is aware no one has yet had the courage to construct an aero engine with cylinders developing more than 50 h.p. each. Some 2½ years ago, as a result of experience with large cylinders on tank engines, the writer was requested or rather challenged by the Air Board to design an engine for aircraft to develop 100 h.p. per cylinder. A complete design was prepared and after much delay a single cylinder unit was built at Farnborough having a bore of 204mm. and a stroke of 280mm. This unit has now been running on and off for over a year. Apart from a rather mysterious failure of the valve gear at first which has never been quite satisfactorily explained, it has given very little trouble, and no trouble at all which can be attributed to its large size. In view of the fact that its compression ratio is only 4.84 : 1 the results obtained are rather extraordinary and constitute, the writer believes, quite a record for so low a compression. This single cylinder unit develops 120 b.h.p. when running at 1,350 r.p.m. with a consumption of only 0.493lbs. per b.h.p. hour at its normal speed of 1,250 r.p.m. corresponding to an indicated thermal efficiency of 31.2 per cent., or within 4 per cent. of the limiting value for this compression and an indicated mean pressure of 150lbs. per sq. inch.



These results will, the writer hopes, help to dispose of the myth that very large cylinders can only operate with relatively low mean pressures and at a low efficiency.

Mr. A. J. ROWLEDGE then delivered the following lecture :—

THE INSTALMENT OF AN AEROPLANE ENGINE.

It has been remarked that more accidents occur due to installation than to engine failure. If this is true, or even partially true, the subject is one that is well worth careful consideration and discussion to see what we can do to eliminate the causes of trouble in view of our responsibilities to the flying public. It is a subject that can be approached in many different ways. We can take the smaller points of the detail arrangement of parts and this is sufficiently important to warrant the whole Paper. Then there is the question of the position of the motor or motors, whether a central engine-room with shaft and gear drive to the

propellers is desirable. We may also consider whether the propeller should be direct coupled to the crankshaft and whether gearing should be used at all. In fact, the subject can be very easily made too wide, and I will limit myself to a few definite points, first by limiting myself to water-cooled engine installations and then as regards data and illustrations to one particular engine.

With regard to the particular engine I am taking the Napier "Lion," as in this case I can be responsible for the accuracy of the data which is easily available to me. I hope people who have comparable data, particularly with regard to air-cooled types, will give their experience in the discussion.

In a complete aero-engine installation the main factors are weight, power and reliability. When considering weight, we should take the whole weight of the power plant, including tanks and fuel.

In talking of power, we should take the thrust horse-power, and if possible deduct the drag due to cooling when making comparisons.

I will take first the part of the subject which is worthy of greatest attention—the detail troubles which may prevent a perfectly good engine from functioning properly.

What are these troubles? They are mainly:—

(1) Failure of the petrol supply.
(2) Failure of the oil system.
(3) Failure of the ignition.
(4) Overheating.
(5) Fire.

I think engine-starting accidents should be included with these, as means can be taken to prevent them with any engine, except perhaps the rotary type.

1. Petrol System.

Now the petrol system is undoubtedly difficult to make absolutely free from troubles, but a little modification and experiment should cure most of them and reduce the care the system requires in use.

The main petrol tank is usually so low that the fuel has to be pumped from it, generally to a gravity tank feeding the carburettors. It is often very difficult to arrange a gravity tank with sufficient head, and the arrangement of a wind-driven pump delivering to a junction box with branches to the carburettor and the gravity tank gives a useful addition to the available head when flying. A cock must be fitted between main tank and the junction box to prevent the pump pumping air into the system when the main tank is empty, and to prevent petrol from the gravity tank running back to main tank when standing. With a suitable pump and relief valve a cock may be fitted between the gravity tank and the junction box. In the Airco machines the cock is combined with the junction box in such a manner that by the movement of one handle the feed can be either from the main tank or the gravity tank, or both. It is necessary to provide an overflow from the gravity tank leading to the main tank to take the excess petrol supplied by the pump. A flow indicator fitted in this pipe will show when the main tank is empty and is often fitted.

Engine-driven pumps will almost certainly come into general use, and this step will improve the reliability. Pumps are usually fitted in duplicate, and especially in large machines a hand pump is also provided to feed the gravity tank.

In very large multi-engine machines, particularly for military purposes, the whole system is much more complicated, but I do not propose to deal with them in this Paper.

2. Oil System.

Oil pipes are a constant source of trouble. There is one sovereign remedy—do away with them. I quite expect one day to see an installation with only one oil pipe from the reserve oil tank to the engine, and for flights up to 3 or 4 hours, none at all. This means, of course, that the oil tank will again become part of the engine. In making this statement I am considering mainly civil aviation machines as certain military ones run under somewhat different conditions, and the same simplicity of arrangement is not always possible.

Sufficient oil cooling is easily provided. All installations of new design should be fitted with thermometers to check the oil temperature.

Good and easily accessible oil filters must be fitted, as they should have frequent attention.

3. Failure of the Ignition.

Ignition failure is usually a matter of the magneto, either due to unreliability of the magneto itself or due to the machine suffering from an oil or water bath or too much heat. With regard to failure of the machine, I am afraid that to go into magneto design from this point of view would occupy too much space for its discussion to be considered in this Paper. Trouble from the other sources will disappear very quickly as more aeroplanes are built.

It is essential to fit two entirely independent ignition systems to ensure reliability, and with the size of cylinder usual in aero-engines the gain in power from having two plugs in each cylinder is considerable.

It is usually possible to find from among the various plugs on the market one that will suit any particular engine and be reasonably reliable.

If the installation is thoroughly gone over on the first experimental machine, the correctness of the general design should be established, so that only the detail parts require attention.

With an adequate supply of petrol the float feed certainly requires attention. We make our floats much too small, with the result that to obtain the necessary effort to close the needle valve they have to be made too thin and flimsy. A little more weight—a few ounces—and I think the float feed can be made beyond reproach as a reliable unit. A float feed can be made to work satisfactorily with a head of only 18 inches if the size is not restricted.

The pipe lines should be carefully studied so that air is not trapped, and then we come to one of the major troubles—the pipes themselves and their joints. The life of rubber joints is much too brief, especially if benzole is used in the fuel, and some change is urgently required. I believe that if we adopt, as has been suggested, a fairly heavy gauge steel tube for our pipes and use rigid joints, we should find a way out of the difficulty. The pipes should be arranged so that deflection is taken in torsion and the tube designed so that it is not overstressed by movements of the frame carrying it.

Carburettor float chambers will again require altering to be strong enough to take the feed connection when all steel pipes are used, and the connection to the petrol tanks will require careful consideration as well to prevent the fairly rigid pipe from causing leaks.

The fitting of an adequate filter is, of course, necessary.

Improved means for telling the pilot the amount of fuel he has left in his tanks is desirable.

4. Overheating.

With respect to overheating this appears to be a matter of having sufficient cooling surface allowed for the worst conditions and fitting shutters to keep the engine warm under more favourable circumstances. Several ingenious arrangements have been made to reduce resistance loss when the whole of the cooling is not required. The Airco 18 and the Fairey installations are both examples of one of the latest schemes, each having the radiator under the engine with shutters in the nose to control the air flow through the radiator.

If the cylinders are smooth they should be used as cooling surface as much as possible, as a square foot of surface here is much more valuable for cooling than a square foot of radiator tube.

A well-arranged water system gives very little trouble, and difficulties under this head should not exist, at all events in temperate climes.

5. Fire.

The first rule to make to lessen fire risk is that the carburettor intakes should be carried outside the cowling to carry any flame from a back-fire clear and that all petrol due to flooding should drain directly overboard. It is also desirable that the engine should have the cylinders grouped as regards mixture pipes, each group having its own carburettor, so that in the event of trouble due to valve failure in one group, the remaining groups will carry on and suck out any fire in the faulty one.

Exhaust pipes require to be suitably carried to prevent overheating of any part of the machine and to be strong enough not to burst open at some inconvenient place.

The magnetos should be of a fireproof type, and all the wiring arranged so that a spark from the ignition cannot start a fire.

The position of the petrol tanks and the arrangement of the pipes are both very important. There should be the minimum amount of petrol piping in the engine compartment, and certainly the lower the carburettors are in the installation, the less the risk that need be run.

When the installation has been made as safe as possible by attention to the above points and to preventing any accumulation of petrol or oil in pockets in the engine compartment, a fireproof bulkhead should separate this compartment from the rest of the machine. Any pipes or control rods that pass through the bulkhead should have fitting bushes.

We shall thus considerably reduce the risk of fire, and in the event of a flame starting it will quickly burn out if it cannot reach any inflammable material.

6. Engine Starting.

Engine starting should always be accomplished without propeller swinging; if necessary, by fitting gearing and a crank handle.

I have very little sympathy with electric starters owing to their weight and complication. An engine should be able to be started as long as there is petrol in the tank and not be dependent on the small batteries that can be carried.

The Lion engine is fitted with what we usually call a gas starter. It consists of a vaporiser connected to the engine mixture pipes by a pipe controlled by a cock. A hand pump is provided which blows through the vaporiser, charging the mixture pipes and cylinders with a suitable mixture for starting. To enable the cylinders to be charged, one each of the inlet and exhaust valves can be

held open. A suitable cock is provided so that the pump can scavenge the cylinders with fresh air to give constant conditions in the cylinders before charging. The usual hand magneto is used to provide the spark for starting.

These engines can always be restarted in the air if the machine has sufficient height by lifting the valves, the engine immediately windmilling. When it is spinning the valves are dropped and the ignition switched on and the engine is restarted.

I confidently expect to see engines started easily from the pilot's seat with certainty in the worst weather, as we can now start our engine under good conditions.

Engine Controls.

All controls should be by rods and levers, and flexible cables should be discarded.

The throttle and mixture strength levers should be mounted together and so arranged that when the engine is throttled down the mixture lever is brought back to the right position, otherwise if the pilot forgets to return it he may stop his engine when opening up at a lower altitude.

I prefer the interconnection to be on the control quadrant and not on the engine, as it reduces the strains in the connections.

The ignition control is probably best coupled to the throttle control as it is certainly a safer arrangement and there is no need for it to be left to the pilot.

Other Points.

The choice oi a suitable propeller is very important as affecting engine reliability.

Personally I favour a machine with a good reserve of power, using a propeller that will allow the engine to develop full power when getting off and climbing.

It is surprising what good results can be attained in propeller design in the direction of keeping down the range of engine revs. One of the best cases I have come across on our engine is from 1,950 stationary on the ground to 2,150 all out flying level at about 120 miles per hour.

This point is particularly important with high compression engines, which are liable to detonate badly if run for long at full power on the ground at low engine revs. This point must be familiar to all drivers of motor cars whose engines pink when climbing hills at low speed.

If an engine is of light weight per b.h.p. and economical when running at light loads—particularly the latter—there is no disadvantage, and a good reserve of power is left for climbing and for maintaining schedule time under adverse weather conditions.

In the maintenance of machines in service it is important to have all parts as accessible as possible, to have as little cowling to remove as can be arranged and that amount easily detachable.

One great advantage of placing the radiator elsewhere than in the nose is that provided a smooth engine is used, it requires little cowling. Our engine, as placed in the Airco 18, has the upper part of the engine exposed, and the plugs can be changed without removing any of the cowling.

ACTUAL INSTALLATIONS.

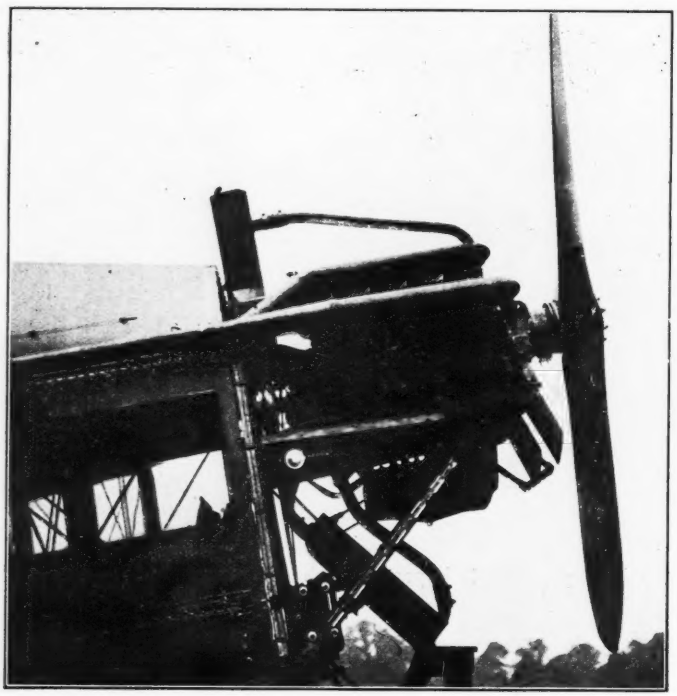
Airco 18.

My first illustration shows the installation in the Airco 18 used on the Paris service of the Aircraft Transport and Travel Co.

The weight of the various parts of the power plant are :—

Motor	860lbs.
Cooling	233 ,,
Tanks	142 ,,
Framework and cowling	110 ,,
Fuel and oil	875 ,,
Exhaust manifold, propeller and miscellaneous	194 ,,

making a total of 2,414lbs. or



Napier "Lion" Engine Installation in Airco 18.

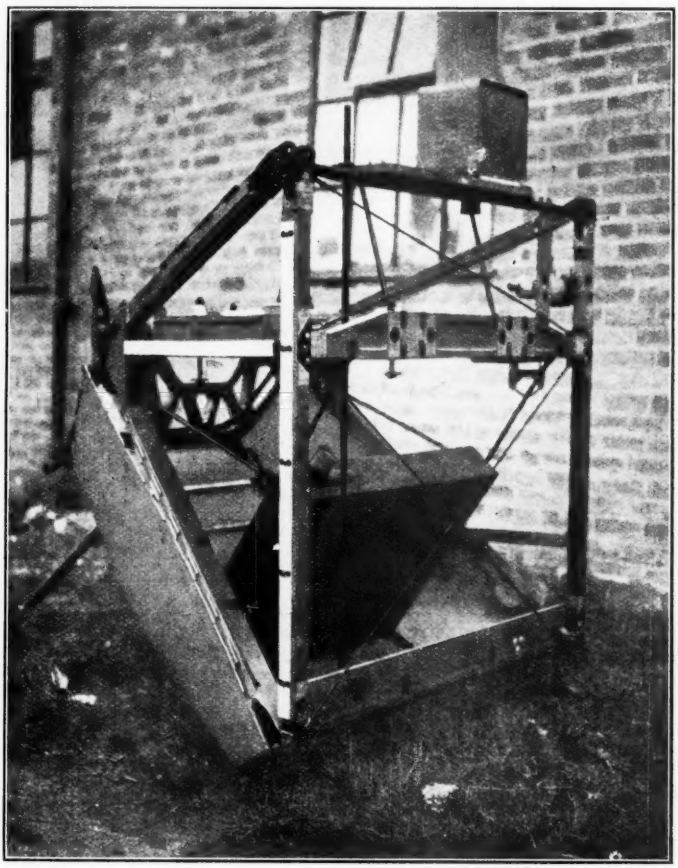
5.36lbs. per b.h.p. including the weight of the whole framework carrying the engine and engine cowling. The amount of fuel used in service is from 20 to 25 gallons per hour, and varies with the weather conditions. The weight of fuel included in the above is sufficient for 4 to 5 hours flight.

The whole framework carrying the engine is detachable by removing four bolts at the corners of the front end of the cabin, making it possible for a spare nose to be kept with the engine installation complete, ready to replace the ones in

service with the minimum delay, preventing the necessity of laying up the machine whilst the engine is being overhauled.

The petrol tanks are carried in the main body.

The engine is started by the special system of the engine makers, the controls



Detachable Nose of Airco 18.

and pump handle being all accessible under the rear of the engine frame, the height of the fuselage from the ground making this a convenient position.

A complete description of this machine has appeared in " Engineering " of August 20, 1920.

I have so far talked of the installation weights as lbs. per b.h.p. including fuel, and this rather hides the importance of the weight per b.h.p. of the engine itself, and I should like to just touch on this question very briefly.

Taking the Airco 18, which has a total flying weight of 6,730lbs. when

carrying a useful load of 1,470lbs.; if the engine weight were increased by ½lb. per b.h.p. or 225lbs., in order to carry the same actual useful load with the same efficiency, that is, with the same flying weight per b.h.p., the h.p. would have to be increased to 533 and the total flying weight by 1,120lbs. to 7,980lbs., making a machine much more expensive to run and of greatly increased first cost, owing to the increase in size.

Fairey Amphibian.

This machine has the engine mounted in the nose. The radiator is mounted in the fuselage under the engine. The reserve water tank is carried in the front of the top plane and the outlet water pipe from the engine is carried through it, being perforated to allow air or steam to escape from the circuit. The tops of the cylinder blocks projecting through the cowling, considerably assist in cooling the engine.

The main petrol tank is carried below the engine level and between the planes. A gravity tank is fitted immediately behind the water tank in the top plane.

The oil tank is carried close to the back of the engine just below the bearers.

The engine controls are all coupled by means of rods to levers conveniently placed in the pilot's cockpit.

Handley Page W.8.

The machine is fitted with two engines, each forming a self-contained power unit comprising engine, fuel tanks, oil tanks, radiator and water.

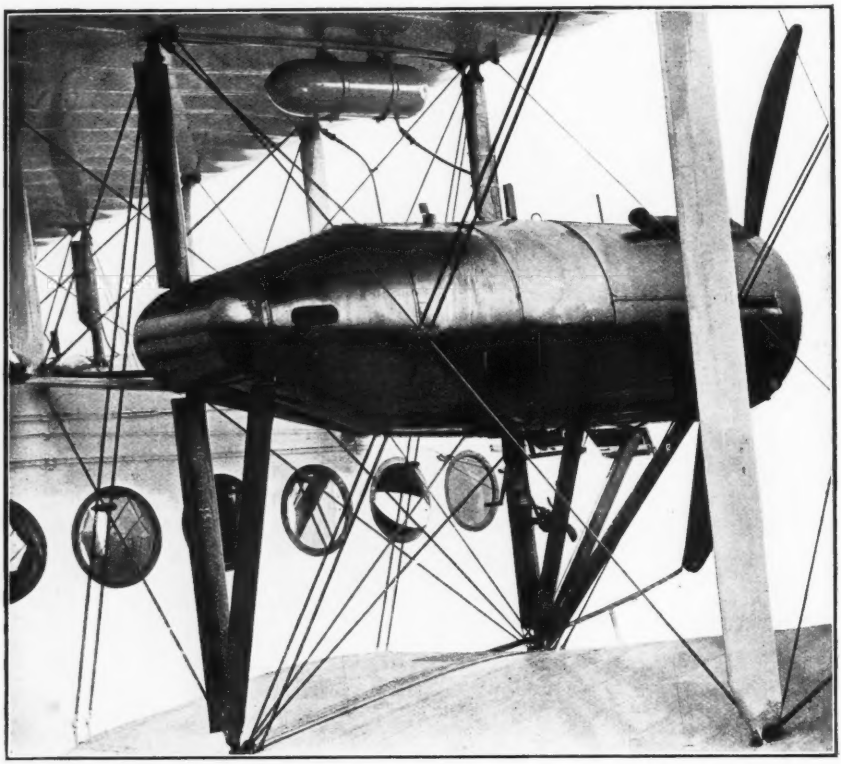
The engine rests on armoured wood bearers which are supported by a triangulated steel tube structure underneath and two vertical tubes above, braced by ordinary R.A.F. wires. This arrangement provides for the engine and tanks being offset outboard one foot from the point where the frame is attached to the plane hinges, thus saving two feet on the folded width of the planes without restricting the propeller diameter. The absence of tubes and bracing above the horizontal tank and engine bearers on the outboard side enables the engine and tank to be removed with the minimum of trouble. The radiator with water tank and altitude shutters is carried by flexible clips from the end of downward extended arms bolted to the front of the engine bearers and stayed at the top to the vertical tubes. A fire-proof partition is fitted which entirely isolates the tanks from the engine. The 10½ gallon capacity oil tank fitted with air cooling tubes is placed across the tank bearers at the rear and connects via a large bore cock with the Napier oil strainer placed alongside. The tank is below the level of the engine connection when the machine is resting on the ground. The main petrol tank is of rectangular section placed between the tubular bearers and fixed thereto by U-bolts. A vertical contents indicator is fitted to the top visible from the pilot's seat and working over a scale 5in. long, is worked by a quickly detachable float arm. The petrol system comprises a large filter with detachable gauze of 35 square inches area placed inside the bottom tube fairing and connected up to main tank sump, from the filter petrol flows to the "Vickers" centrifugal wind-driven pump which feeds straight to the carburettors via a pilot-controlled cock, the surplus passing up to the gravity tank under the top wing and then overflowing from there back to the main tank via the flow indicator let into the fairing of the vertical tube and visible from the pilot's seat.

Two additional small A.G.S. type filters are fitted close up to the carburettors and a hand pump is provided in the pilot's cockpit for use when starting up. In the event of the pumps failing the gravity tank feeds to the carburettors until empty, or one pump can be made to supply both engines via the fuselage. A cock is provided for draining the gravity tank when machine is in dock. The engine starting handle is fitted to a cross shaft below the cowling and drives to

HANDLEY PAGE TYPE "W.8"

C. A. OF NAPIER "LION" ENGINE MOUNTING.

the engine by chain. The starting gear, consisting of vaporiser, pump and starting magneto, are shown on the drawing. The starting clutch and valve lever are fitted with cables and rings placed in a convenient position. The aluminium cowling is fitted to the framework in panels which can be quickly hinged open or removed altogether. A platform is built into the bottom plane for use of mechanics.



Installation of Napier "Lion" Engine in Handley Page W.8.

Vickers' "Viking III."

The engine is located high up in the space between the upper plane and the deck of the hull, the principal supports being four steel tubular struts which spring respectively from the four main plane strut fittings on the deck. In front elevation the main plane struts diverge from the deck fittings, and the engine struts diverge in such manner as to support the longitudinal engine bearers at the transverse pitch defined by the holding down bolts of the engine. The bearers are of ash, being connected transversely by steel tubes at their front and rear extremities, and all four sides of the truncated pyramid thus formed are braced with streamline wires.

The engine is mounted as a pusher, so that the power end is the rear with reference to the machine.

The radiator is supported on trunnions which are mounted on forward extensions of the ash bearers, tubular stays being carried from the upper part of the radiator casing to the under side of the front main plane spar. The whole of the front surface of the radiator is shuttered.

The three engine manifolds conduct the exhaust gases forward, *i.e.*, towards the radiator, this direction being reversed by the application of U-shaped extensions which discharge the gases backwards at a safe distance from the propeller.

Twin oil tanks are slung externally along the ash bearers, and the Napier oil filter is clamped upon the front transverse tube at about the same level.

The engine controls are actuated by a positive system of push and pull rods which pass up from the pilot's cockpit by the front starboard leg of the mounting and are connected up to levers on transverse shafts supported by the brackets which support the radiator.

The starting shaft of the engine is extended to pass through a bearing on the front port main plane strut, and is worked by means of a crank handle of standard type.

The Napier vaporiser is supported on a bracket high up between the radiator and the engine, the valve operating lever being connected through an extension to a vertical tension rod which passes down behind the radiator and is fitted with a T-handle.

A low trough-shaped cowling is applied to the engine bearers and fairs in the lower part of the radiator, oil pipes, etc., but the cylinder blocks and manifolds are completely open to the air.

The air intakes, of aluminium, are carried down through the cowling, converging towards the centre in order to avoid screening by the struts.

The Vickers' wind-driven centrifugal petrol pump, which supplies the power for the petrol system, is located on the rear port main plane strut.

The weights of the various parts of the power plant are :—

Motor with turning gear	890lbs.
Cooling	275 ,,
Tanks	78 ,,
Framework and cowling	75 ,,
Fuel and oil	577 ,,
Exhaust manifold, propeller and miscellaneous	170 ,,

making a total of 2,065lbs.

or 4.58lbs. per b.h.p. The fuel economy of this machine is very good. At Martlesham in the Government trials it flew at 82 m.p.h. with a fuel consumption of 14.2 gallons per hour.

Westland Six-Seater Limousine.

The engine is installed in an all steel separate tubular mounting, rigidly braced by cable and attached to the front fuselage by 10 bolts.

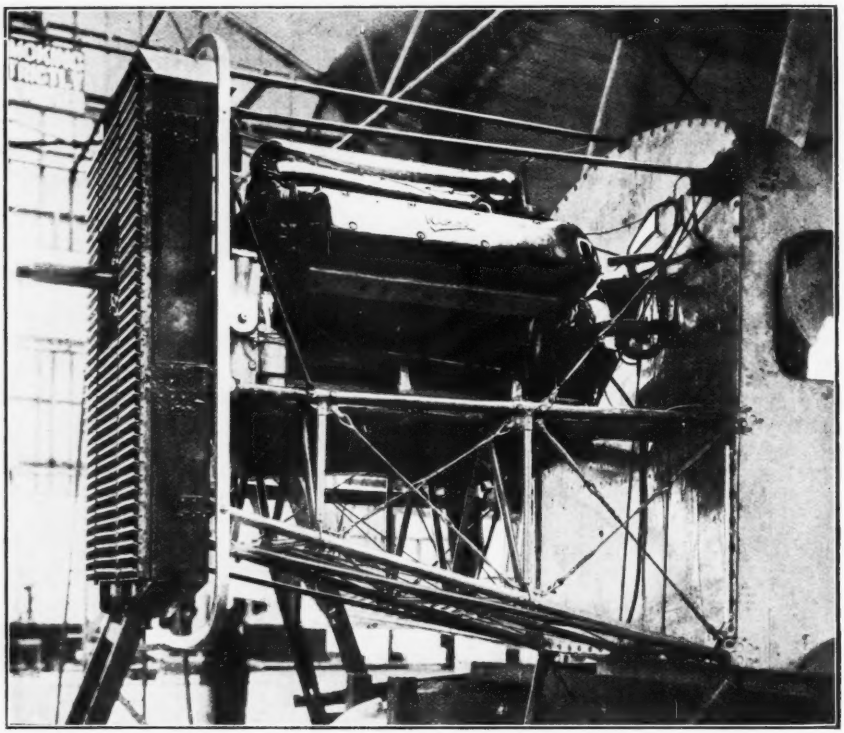
The engine is directly bolted to the two main bearer tubes by six bolts, and when in place is very accessible.

The top and bottom side tubes of the structure are arranged so that their extensions form the support for the radiator.

The cowl and cowl frame are independent of and are not supported by the radiator, making the removal of the latter a very simple job.

The whole of the engine installation is separated from the rest of the machine by an aluminium and asbestos bulkhead; in fact, fire prevention has been studied

very carefully in this machine. The carburettors, of course, suck from outside the cowling. Two main petrol tanks are carried, one on each side under the bottom wings; each is fitted with a wind-driven pump delivering the fuel to a gravity tank carried in the front of the top plane, whence the carburettors are fed. None of the pipes enter the main fuselage behind the fireproof bulkhead; the pipes are very accessible and the renewal of the jointing material is much simplified.

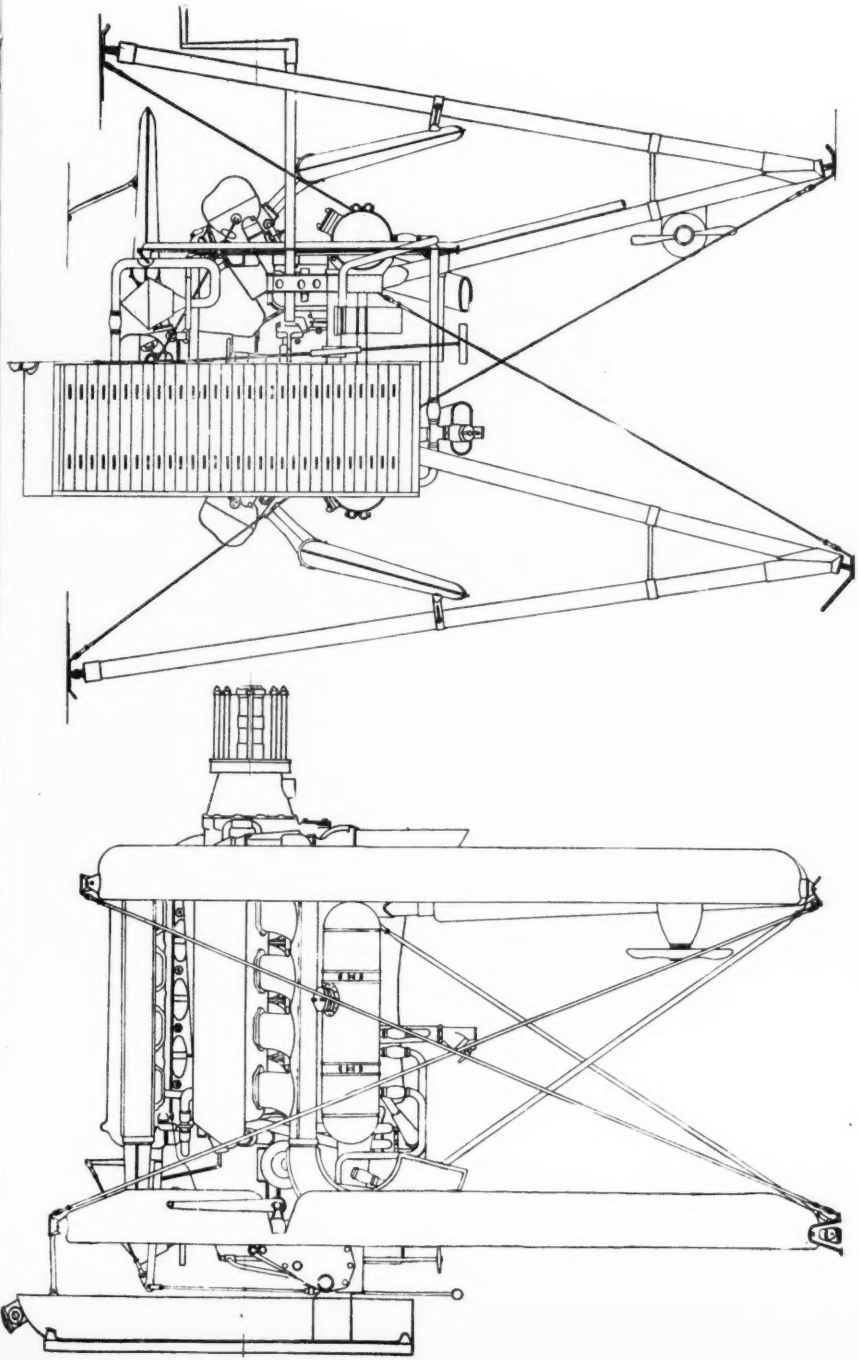


Westland Napier 6-seater Limousine (Government Aircraft Competition, 1920, small class—engine installation).

The engine fitted in this machine for the Government trials was fitted with gearing for a crank handle for starting, but no handle was fitted, the gas starter being relied upon with very satisfactory results. All the controls and the charging pump are placed so as to be get-at-able from the pilot's seat. A hand turning gear is now fitted to these engines for starting from cold in bad weather, keeping the gas starter for favourable conditions and as a very efficient primer in connection with the hand turning gear.

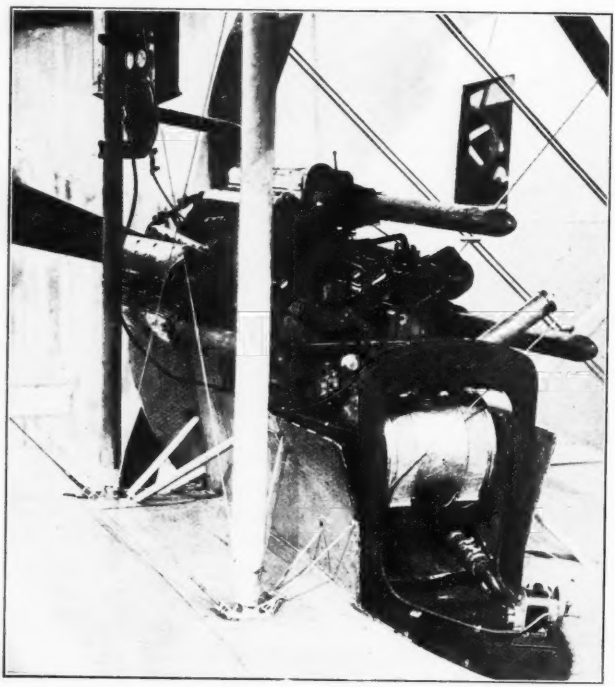
Boulton and Paul " Lion " Twin-Engine Machine.

I am including this illustration particularly to show the method of dealing with the exhaust designed by Mr. North. This consists of ribbed aluminium castings bolted to the cylinders with steel pipe extensions. The ends of the



NAPIER LION ENGINE MOUNTING IN VIKING MKIII

pipes are closed and the gas escapes through narrow slots. This arrangement is quite effective as a silencer; the castings and pipes being in the slip stream are kept surprisingly cool, and this system appears to be worth much wider trial.



Installation of Napier "Lion" Engine in Boulton and Paul twin-engine machine.

In conclusion, I should like to thank particularly the various firms who have so kindly placed illustrations and data at my disposal, which have been invaluable in the preparation of this Paper

DISCUSSION.

Brig.-Gen. R. K. BAGNALL-WILD said he had not had an opportunity of seeing the Papers before, so he would make his contribution in writing.

Wing Commander T. R. CAVE-BROWN-CAVE said the two Papers were extremely valuable. Mr. Ricardo's covered a wide range of experimental work, mainly directed to showing how it would be possible to obtain greater fuel economy. The importance of fuel economy was not always realised and some figures based on recent considerations of airship transport would be of interest. The saving of the *price* of a pound of fuel was comparatively unimportant. The important

gain was that by eliminating a pound of fuel a pound more merchandise could be carried, and the saving was the price of carrying a pound of merchandise the whole distance. To take a typical airship route, the cost of carrying one pound was 2s. 10d. That might be regarded as too low, but if one liked to take it as 10s. his point was even clearer.

A question had arisen whether an explosive mixture of hydrogen and air was more easily ignited than one consisting of nearly pure hydrogen. He wanted to ask Mr. Ricardo to give some more information on that point, and also whether dilution with nitrogen or oxygen would increase or decrease the difficulty of ignition. Mr. Ricardo's Paper showed great originality. Taking it in conjunction with his Paper read recently to the British Association, one realised what enormous progress was being made. He was sure those who had not read the Paper, but had only heard the abstract read, did not realise completely what an amount of information and advance there was in it. He knew of no more refreshing experience than to go to Shoreham and see in Mr. Ricardo's laboratory the admirable arrangements for research work, and when, after that, one saw his two Papers, one realised the speed and value of the progress being made. It did seem that something really good was going on in engine research.

He was much pleased with one point, particularly, in Mr. Rowledge's Paper. The description of the machine in which the whole engine and its fittings could be removed by the withdrawal of four bolts announced a very valuable development. He had pleaded at a lecture of last session for airship power cars to be made as easily changed as the locomotive of a railway train. Mr. Rowledge's design certainly came very close to that ideal.

Major H. E. Wimperis said some members of the Society would be chiefly interested in the development of the internal combustion engine as such, whilst others were more concerned in what to do with the engine when they had got it. Speaking as one of the former class, he felt now that any one of the great engineering institutions would have been glad to have had Mr. Ricardo's very able Paper. This Society was therefore very fortunate. It was interesting to come once again across a discussion of such things as stratification and quality "governing." The question of quality versus quantity regulation was an old one and it was now being raised by Mr. Ricardo for aero engines. With the earlier kinds of engines it was a very vexed question. The aero engine, like the motor car engine, had adopted the regulation of power by varying the quantity of the gas; we were now asked to consider whether it would not be of advantage to vary the mixture, *i.e.*, the quality instead of the quantity. Would Mr. Ricardo, he asked, expect to find with the aero engine the difficulty with ignition setting which was always found by those who tried quality governing with the predecessors of the aero engine? The question with regard to stratification was important because the reliability of the aero engine depended very much on the ability to run at cruising speeds—not at full power. To go to the other extreme, the motor car ran at 30 per cent. full load most of its time. One started at 100 per cent. and went down to 90, 80 and 70, and as one tried to get a better and better figure, it became more and more important that the thermal efficiency should be maintained. Mr. Ricardo now suggested that the adoption of the stratification method of fuel supply would improve the efficiency. As to the effect of the addition of exhaust products, he would ask Mr. Ricardo a difficult question. We all know that the admission of a fraction of the exhaust products had the effect of minimising the tendency to detonation, but could he say why?

Air Commodore H. R. M. Brooke-Popham congratulated the audience on their good sense in coming to listen to these Papers. Mr. Ricardo's Paper was particularly valuable in showing the possibilities of progress. It was an important thing to show the public that aviation had by no means come to the end of its

tether, because there was rather a tendency among certain classes to think aviation had shown all it could do, and had not quite come up to what was claimed for it. They should take every opportunity of showing they were only just touching the fringe of the subject. He was struck by the mounting Mr. Rowledge showed for the Airco 18. That was particularly important from a military point of view and it should be brought into other machines. The time taken in changing engines had an important effect on the number of machines available for work each morning. If an engine took 48 hours to change it meant that a larger proportion of aeroplanes was out of action every day. Sometimes in the last war repairs could not be effected in a night, because there were delicate adjustments and fitting to do, but if machines could be designed so that the engine could be changed by moving four bolts and putting four bolts back again it was an enormous step in advance. Magnetos were not as reliable as they should be. The difficulty was not electrical, it was mainly lack of attention to mechanical details. He saw no reason why the British magneto should not be a great deal ahead of any German magneto. We knew the electrical defects, and it was simply a question now of paying more attention to mechanical details.

Mr. CHORLTON (Sir Wm. Beardmore and Co.) added his congratulations to the Authors. He thought the question of the installation was almost more important than that of the engine. The installation in the Airco 18 was a very excellent arrangement with a fire bulkhead and the whole of the engine and tanks and gear demountable very quickly. No doubt that type would be further simplified and improved. He imagined that we should soon have aeroplanes in which there would be an eyebolt at the top of the engine unit, so that a crane run overhead could lift the whole section off, so that it would be taken away and another take its place in an hour. He believed that something like this would be essential if flying was going to be a commercial success. There was another aspect different from those the Authors had dwelt upon. Two important considerations were weight and quality. It was rather unsatisfactory after hearing such excellent scientific Papers as they had heard, to know that on the Paris service the light weight engine, if made reliable, was a better commercial proposition than the economical engine. So it struck him that if Mr. Rowledge were to go out and design an extremely light weight engine and get it made at the Napier works he would get still better results than he had attained so far. It had been shown clearly that the best engines had been made by those firms accustomed to making the best class of motor car. That had been so throughout the country. It was no reflection on the designer, but it was a fact. When one came to economy, the saving that could be made in economy on flights of three hours was much smaller than the gain by having the least possible weight of engine. The price paid by the passenger was so high, as Commander Cave had found out, that the gain was great for long flights, for short flights it paid to go in for the light engine. He thought Mr. Ricardo's remarks were more applicable to airship work than to the standard aeroplane flights. With regard to the doping of fuel, it was evidently going to end up by being the regular thing, and a standard spirit would be prepared which would enable those high efficiencies to be obtained. It was curious that they were getting more by dope than by anything else. In reference to stratified charging, Mr. Ricardo and he years ago spent a great deal of time on this, and on a large engine, in 1912, he got with stratified charging a consumption of under 6,000 B.Th.U., which was, and he thought still continued to be, a record. He was entirely with the Author in saying that it was the best thing to do, and it met the cruising conditions for long flights admirably. Again, in his opinion, it was more the thing for airship work than for aeroplanes. With regard to increase in the expansion stroke—longer expansion than compression—that was another excellent thing to do; and it was possible to do it in another way that had possibly other advantages. The stroke in a radial engine could be varied by an eccentric on the crank pin, and one could start a flight with a long suction

stroke and short power stroke and continue the flight with a short suction stroke and long power stroke, varying the power and the economy greatly. Then they had their old friend cooled exhaust. This nearly always cropped up when they were in difficulties and cured them. Though it was an ancient thing it had been left for Mr. Ricardo to put it in its right place and make the most effective use of it. He had known it and used it for 15 years, but to a limited extent, for coke-oven gas, where there was 40 to 50 per cent. of hydrogen, was not safe running, for pre-ignition could not be got without it. It was only in the last year or two that Mr. Ricardo had taken it in hand and shown what increased economy might be obtained by its now scientific use. On the question of large cylinders, Mr. Hamilton of the Premier Gas Engine Company had worked up to between 120 and 140lbs. mean pressure for 20in. cylinders a long time ago, so they should not be deterred from going to something larger even than the 8in. cylinder Mr. Ricardo had spoken of.

Captain G. T. R. HILL said the detachable type of engine mounting described by Mr. Rowledge came very near the ideal of quick change and quick replacement, as shown by the rotary engines. In his squadron during the war they had De H.2's with 100 mono engines and they got their engines changed during the night without difficulty. This could not be done anything like so easily with other engines.

The whole question of installation seemed rather to have fallen between two stools. The engine designers produced an engine and the aeroplane designers produced their machines, and there was not enough co-operation between the two in modifying their designs to fit together easily. For example, the Hispano-Suiza engine, which was widely used at the end of the war, was not a convenient engine to build into a fuselage. The flange of the engine crankcase, which was bolted on to the fuselage, was much too narrow to fit the longerons of the machine, and engine bearers with narrower centres had to be fitted between the longerons and much cross-bracing put in to make the structure stiff enough to connect the engine rigidly with the longerons. In his opinion, the best way to make an engine easy to fit to a fuselage was to follow what the Rolls-Royce makers had done, that was to fit feet which could be bolted on to the crankcase. These feet could be made of variable length, according to the design of fuselage, and could be clamped on to the longerons at any points desired. He thought the nose of the fuselage should be made quickly detachable from the rear portion, and instead of having spare engines one could have spare noses of fuselages, complete with radiator and oil tank, ready to fit on to an aeroplane whose engine required overhaul. These noses could be bolted on to a dummy fuselage for test purposes, and run up with a propeller of small diameter, which would give the high velocity of slipstream necessary for sufficient cooling with the standard radiator when run on the ground.

With regard to the position of the engine controls in the cockpit, in his opinion they had got to the stage where they ought to have a standard position of the throttle lever and switch. These, he suggested, should always be on the left of the pilot, close to his left hand, so that no groping about would occur in an emergency. In two and four-engine machines there should be one master switch to switch off all the engines in case of need.

He would like to see a complete gravity system for the petrol coming into more general use. Most forced landings were due to petrol failure and petrol failure was practically always pump failure, and pumps never could be made as reliable as gravity. Against the all-gravity system it might be urged that the tanks in the wings were not of the optimum shape from a lightness point of view, but that was so small a disadvantage compared with the reliability obtained that he thought a move should be made in that direction.

As regards the desirability of using a propeller which had nearly constant revolutions at all speeds, this was realised with a coarse pitched propeller, and as such he believed it was theoretically rather less efficient than a fine pitched one. In practice, however, it did not appear to make much difference to the performance of the aeroplane, and he much preferred flying with a coarse pitched propeller, especially in war time, as the engine did not tend to race so badly in a dive.

He had analysed the petrol consumption results obtained at Martlesham on the land-going machines in the recent Government competition, and he could not make the consumptions, on the whole, come down to anything like the figures given by any maker of engines. There was little data available of actual consumptions in the air. When making an analysis of such as the Martlesham figures there was always a certain amount of guesswork, but he had not been able to make any of the consumptions come to appreciably less than 0.6 pints per h.p. hour and many stood at nearly 0.8 pints. That was a point to which more attention should be paid, and possibly it might be necessary to apply a correction factor to the engine makers' figures when estimating what the actual consumption would be on a commercial service.

Col. BRISTOW said, as he had not had an opportunity of looking at the Papers, he would contribute a written article to the discussion. A point he would like to refer to was the question of the propeller. On some machines fitted with Rolls-Royce engines it was not unusual to find when the machine was leaving the ground that the propeller was turning at just about 1,500 r.p.m., and the ground engineers seemed satisfied. The maximum h.p. from the engine was delivered at about 1,900 r.p.m. and it seemed to him that they could get a safer performance on the climb and absence of detonation on the engine with propellers of smaller ranges of speeds. Other difficulties would arise with steel piping for benzol, as steel was susceptible to benzol. The best results had been obtained by lining the steel with lead. Several aspects of installation did not receive enough attention, some of which were electrical. Many makers employed magnetos with a rotary spark-gap instead of a wipe contact with a carbon brush. There one got a static discharge in the line which led to the hand-starting magneto, and any breakdown of the insulation in that line caused a high frequency discharge with consequent risk of fire. The distributors themselves in the magneto were not a gastight fixture and there again one had a weakness in the installation. Steps should be taken as rapidly as possible to do away with the fragile piping between the top of the petrol tank and the engine. It had been demonstrated that fires had been caused through the fracture of that pipe, and yet it was retained and in multiple engine machines it was considerably increased in length.

It is rather remarkable that although an enormous amount of time and money has been expended on the development of the petrol engine, yet no real alteration in the underlying process has yet been made. We still take petrol as the fuel, mix it with air in some form of carburettor, ignite it electrically over a piston and cool the combustion chamber. This process seems as if it is bound to entail the presence and use of a multiplicity of parts difficult to reliably construct and maintain, and in view of aero engine requirements in the future it would almost seem necessary to find some means of changing the underlying process in order that the many difficulties inherent in the present type of engine may be eliminated.

The CHAIRMAN stated that an interesting contribution, giving figures of high efficiency obtained with air-cooled cylinders, had been received from Professor Gibson and would appear in the printed discussion.

Captain Hill's analysis of Martlesham results agreed very closely with his own. It did not seem possible to rely upon a fuel consumption during flight of less than 0.6lbs. per b.h.p. hour. This corresponds approximately to a range,

at a cruising speed of about 80 m.p.h., of 28,000 W miles per gallon of fuel carried for an average machine. If his recollection were correct, tests at Martlesham on machines ranging from the Sopwith Pup to the big Handley Page machine confirmed this formula. Later, and more heavily loaded, machines might do better. The high fuel consumption in the air was partly due to carburettor design and partly to the fact that economy depended so much on the pilot. If this were taken into account the importance of Mr. Ricardo's experiments on increasing thermal efficiency was greatly enhanced. The use of a "stratified" charge had many advantages for aircraft engines, and Mr. Ricardo seemed to have got a long way on the road to success.

Mr. Rowledge's Paper was full of interesting detail. He (the Chairman) was rather inclined to disagree with him as to the importance of leaving cylinders exposed. It was quite possible that a big gain in efficiency might be obtained by enclosing the engines entirely, except for radiators, and using a different form of body; but more aerodynamic research was needed before such questions could be decided.

Mr. RICARDO, in reply to the discussion, said Commander Cave asked as to the effect of admitting exhaust products upon the ignition. So far as it was possible to see it had no effect. Air had to be ignited there if there was any large power. The ignition timing with stratification in all the diagrams he had shown, whether on lightest or fullest load, was the same. The expansion line was equally vertical at all loads, due to the fact that the combustible part of the charge was in a state of violent turbulence. With producer gas it was only possible to get satisfactory results on stratified charging over a narrow range; with exceedingly rich fuel and very small quantities the problem was very different and much easier. Major Wimperis asked why cooled exhaust gases stopped detonation. He thought it was simply a braking effect which slowed the normal rate of burning, apparently from purely mechanical causes, separating the particles of air and fuel from each other. (The CHAIRMAN: "It lowers the maximum temperature." Major WIMPERIS: "Very little.") Mr. RICARDO: "I don't think that will explain it."

Mr. ROWLEDGE, also replying to the discussion, said he agreed that most of the magneto troubles were mechanical, and he thought if the makers could be convinced that the peacetime requirements were worth their while to supply, they would quickly get good results.

Mr. Chorlton raised the question of the two important considerations—weight and quality. Although in the abstract of the Paper the Author did not refer to this point, the matter is referred to in the description of the Airco 18, and the Author read this part of the Paper, pointing out that in commercial machines where the load per h.p. was fairly high, the effect did not show up so rapidly as in the high performance military machine. When one got down to about 10lbs. per h.p. flying weight, the necessity for saving every ounce of weight of the engine was much greater. In the analysis of weights given, he had included the pilot in the structure weight.

Captain Hill referred to the question of consumption. The figures appeared to him quite good. The Vickers "Vimy" used 14.4 gallons per hour total consumption running considerably throttled. It was only flying 83 miles an hour, although it could fly at 120, so of course the h.p. was low compared with what the engine was capable of. It was a good performance to fly with less than .6 of the full power consumption.

The gravity system of petrol supply is an excellent one and would save trouble, but it is open to objections. Colonel Bristow objected to it on the score of danger from fire and on many machines it would be difficult to fit, as the engine was placed too high for gravity flow to be reliable.

On the motion of the CHAIRMAN a vote of thanks was accorded the Lecturers and Air Commodore BROOKE-POPHAM moved a vote of thanks to the Chairman.

Professor A. H. GIBSON (*communicated*): I would wish to express my appreciation of Mr. Ricardo's very suggestive Paper and to concur regarding the importance of the various lines of research suggested therein.

Regarding the present stage of the art of aero engine design, the best of the modern engines are, as the Author points out, capable of giving thermal efficiencies so near those theoretically possible, that no further appreciable improvement in this respect is possible without some modification of the present cycle. The following results from a number of engines tested by the writer during the past two years, which are the best weak mixture results obtained from these particular engines, show this perhaps even more strikingly than the figures given in column 4 of Table 1 of the Author's Paper.

	Engine.	Comp. ratio.	Thermal eff. on I.H.P.	Value of $1-(1/r)^{.250}$	Value of $1-(1/r^{.295}$	Ratio of actual eff. to air cycle eff. with variable sp. heat.
A	100 × 140 mm 1600 r.p.m.	4·7	·334	·321	·367	·91
B	100 × 140 mm. 2500 r.p.m.	5·1	·337	·335	·382	·88
C	5½in. × 6½in. 1650 r.p.m.	5·0	·342	·332	·378	·91
D	6in. × 8in. 1450 r.p.m.	4·5	·316	·314	·359	·88
E	5in. × 7in. 1500 r.p.m.	5·3	·329	·342	·389	·85

The first four of these engines are air cooled, the last is water cooled. It will be seen that in the air-cooled engines the thermal efficiency is in every case slightly greater than is given by the expression.

Incidentally, it should be noted that in an engine having different compression and expansion ratios, the efficiency depends both on the ratio of compression and expansion and not solely upon the latter, although this is the more important of the two. Thus, in the case instanced by the Author, of an engine having a compression ratio of 4.85 and an expansion ratio of 8.0, the efficiency would be approximately 0.44, as compared with 0.38 with expansion and compression ratios each equal to 4.85, and 0.46 with ratios each equal to 8.0.

The lines of development suggested by the Author refer to

(*a*) The use of a fuel of high toluene value, with a view of enabling the limits of compression ratio to be raised to as high a point as possible.

(*b*) The use of cooled exhaust gas, with the same end in view.

(*c*) Working with a stratified charge.

As regards (*a*) the researches carried out by the Author and other investigations have already had valuable results, and further investigation will probably lead to further developments in this respect. There does not appear, however,

to be much prospect that any mixture suitable for high altitude work will enable a compression ratio greater than about 6.5 to 1 to be attained at full throttle under ground conditions.

Regarding (*b*) the possibilities appear to be much greater. It would be interesting, however, to know whether the reduction of the rate of burning, due to the addition of inert gases, detracts from the possibility of operation at such high speeds as are common in aero engines. Also whether the addition of such gases requires to be kept within very narrow limits in order to ensure satisfactory operation. In the latter case any sticking of the control valves or any sooting up of the supply pipe might readily render the engine unsafe, either through insufficient or too great dilution of the charge.

Regarding (*c*) also the possibilities appear to be great. Here again it would be interesting to know whether the system has been tested at high speeds. The method would appear to be excellently well adapted for use in slow speed engines. It appears somewhat doubtful to what extent the total heat losses to the walls would be reduced, since the differences of temperature throughout the whole mass of working fluid would be considerable, and the temperature of that part of the charge actually burning would probably be little less than in normal operation. There would also appear to be a strong probability that owing to diffusion at the boundaries of the air of dilution and of the combustible mixture, some part of the mixture would be too weak to burn, and that some of the fuel would be lost in this way. This, however, is a point which will depend greatly on the cylinder design, and can only be settled by experiment.

Other lines of development, additional to those suggested by the Author, would also appear to merit attention. Among these may be mentioned the possibility of developing a practical dual combustion cycle, with combustion partly at constant volume and partly at constant pressure. Such a cycle offers certain theoretical advantages,* and should be well adapted for utilising the high flash point having aromatic hydrocarbono derived from kerosene.

Apart from the development or modification of existing cycles, much detail research work can still, with advantage, be done with a view of bringing the performance of the average aero engine into line with the best of its type. The positions of the sparking plugs, the type and reach of the plugs, the arrangement of the induction system and of the inlet and exhaust valves, all affect the performance to an important extent, and their exact effect requires much further investigation.

* W. J. Walker. Proceedings of the Institution of Mechanical Engineers, December, 1920.

DEVELOPMENT OF GIANT AIRCRAFT IN GERMANY.

SECTION 2.

German Giant Aeroplane Performances.

It is extremely difficult to obtain reliable data concerning the actual performances of German giant aeroplanes, and it will therefore be better for our purposes to confine ourselves to generalities without the use of actual figures, whose reliability may be open to question.

In the first instance as regards "speed," we find within each of the two "A" and "B" type designs, that the speed diminishes as the number of motors increases. That is to say, a *two*-engined "Type A" aeroplane will have a greater speed than a *four*-engined "Type A2" machine, with conditions as regards the horse-power loading and wing loading approximately the same.

Exactly the same rule is distinguishable in the case of the "Type B" machines. In the case of the "Type A" machines this result is obviously to be expected, firstly, on account of the extra head resistance introduced by an increased number of motors when exposed to the wind; and secondly, on account of propeller "interference" and inefficiency.

One has to go more deeply below the surface to locate the reason for this drop in speed where "Type B" machines are concerned. The real reason is however clearly due to increased weight of engine and transmission system, coupled with the approach of structural limitations arising from the too great concentration of "weight." Nevertheless, the speed of the "B type" machines is on the whole higher than their corresponding rivals of the "A type."

Generally speaking, the speed of the *largest* "Type A" machines may be taken as being 130 km. per hour, and in the case of "Type B" machines about 140 km. per hour. In neither case is the speed as high as is desirable for a first class military machine.

As regards climbing capacity, we find that in case of the *largest* machine the "ceiling" is reached in both "A" and "B" types at a height from 6,000 to 7,000 feet. This is again very low, so that we may say that the "performances" of the larger German giants are at first sight very poor. It must, however, be remembered that these machines carried a very high proportion of useful load, and were, by comparison with smaller machines, very heavily loaded. (The bomb load of the standard "Type H" four-engined machines amounted to 3,000 kilograms.)

Range and Duration.

The largest German giants in general use at the close of the war carried under normal conditions about 6½ hours fuel. It must be remembered, however, that the duration of flight could be prolonged very considerably by the addition of extra tanks and the corresponding reductions of the bomb load. So that the maximum duration of these machines (when carrying no bombs) would be nearer twelve hours than six hours. The majority of "Type A" machines were arranged to accommodate extra tanks, which could be rapidly fitted when required.

In the case of "Type B" machines—due to the lower percentage of useful load—the "duration" figures must be taken as being somewhat lower than with the corresponding "Type A" machines.

So far as the maximum figures for "range" are concerned, we may safely say that the ordinary standard German (war) giant had a normal "radius" of about 400 miles, and a maximum possible "radius" of about 800 miles, when flying in still air. In other words, these machines could in still air cover 800 miles in a straight line when carrying their bomb load, or 1,600 miles when carrying no bombs.

When compared to the sensational "record" endurance flights, as for example the trans-Atlantic flights, these figures do not appear to be very good. The figures given, however, correspond to military circumstances as opposed to "competitive" conditions, and the load carried includes a vast quantity of armament gear in addition to the actual bombs, fuel and crew.

We must observe that the above figures correspond to four and six-engined machines, equipped with a total horse-power of between 800 and 1,500. What then would be the effect, if we could, without affecting the total horse-power, reduce the number of engines from four or six to one? Both theory and practice agree in forecasting a higher "performance" and a greater "range." We should lose only in respect of "reliability"; this is a question, however, of which we shall treat elsewhere. It is important to insist that in principle the fewer the number of engines the greater will be the "performance" and the larger the "range." We must remark here that Germany, in endeavouring to prepare a "heavier-than-air" reply to the American declaration of war, commenced to build a giant aeroplane intended to bomb New York (from Europe), and at the same time commenced to experiment with 1,000 h.p. engines with which to equip this machine.

A vast extension of "range" is to be expected from the development of the super-compression motor with its high fuel economy and great efficiency at high altitudes. It is not improbable that from this item alone it will be possible in the very near future to count upon a 30 per cent increase in the "range" of giant aeroplanes.

(d) PERFORMANCE, ETC.

Note.—In relation to a possible advantage accruing from the use of "Thick" wing sections.

During a visit to the Junker factory at Dessau, Professor Junkers, in demonstrating his method of obtaining wind tunnel results, drew attention, while discussing the experimental results of "thick" wing sections, to the fact that the employment of a thick section restricted very considerably the movement of the centre of pressure. Statements of German "Junker" pilots to the effect that the "Junker" was exceptionally steady in bad weather would seem to corroborate this statement.

The point is therefore likely to be of considerable importance in very large machines, which up to date have been notoriously "heavy-handed" in bad weather, not only on account of the increased stability which is the natural sequence of such circumstances, but also on account of the possibility of saving weight in the tail planes and elevators, and in addition as adding to the comfort of the passengers and pilot, or in the case of military machines, insuring a better "bombing platform." This fact also mitigates to some extent the disadvantages of "cantilever wings" in necessitating a relatively large chord, as in ordinary circumstances the greater the "chord" of the planes the more uncomfortable does an aeroplane become in bad weather.

Section (*a*), Crew and Disposition of Defence Armament in the Machine.

As a rule the war crew for German giant machines consisted of two pilots, two mechanics, one navigator, and one machine gunner—making a total of six

men. Of these, the two mechanics were also trained machine-gun operators, and the machine gunner may be regarded as an extra mechanic. The actual composition and numbers of the crews naturally varied slightly in accordance with the individual circumstances of operations or bomb raids.

Actually, so far as war experience goes, we are obliged to rely entirely on information in regard to " Type A " machines only, as none of the " B Type " machines seem to have been in use at the front, and our " C Type " had not yet emerged from the preliminary small-scale stage.

The four-engined and five-engined " Type A " machines carried a formidable armament in machine guns placed as follows:—One in the fore-part of the fuselage, two in the after-part of the fuselage, one of which fired downwards through the fuselage, the other being on top of the fuselage. In addition to this, two other machine guns were carried, one in either engine nacelle. The engine nacelle guns were portable and could be fired either outwards from the engine nacelle itself or from a ring mounting fitted in the top plane immediately above.

This disposition of the guns gives an admirable field of fire, particularly in a backwards direction, since the two top plane mountings in the wings are clear of the tail planes and fuselage.

It is doubtful if this concentration of machine guns was really necessary, but at the same time it is worthy of note, particularly in view of the German " Gotha " casualties at the close of the war from the action of Entente night-flying " Scouts."

As regards the crew of these giant machines, one cannot but be struck with the number adopted when considering also the total horse-power of the machine. At the same time it is difficult to imagine any reduction which would not seriously hamper the efficiency of the whole as a fighting unit. While this matter may appear somewhat trivial, it is in reality of considerable importance, since if six be the minimum number of crew required for a " giant " machine, it is a clear indication of the fact that a " small " giant machine of medium horse-power is not only unlikely but certain to be useless. Indeed, on a rough practical estimate one might confidently affirm that if a machine must carry a crew of six, it must be of at least 1,500 horse-power in order to carry the necessary additional load of bombs and fuel.

The question of crew and defensive armament for giant machines is extremely important in view of the weight involved, which in the case of six men and five machine guns with ammunition totals about 1,500lbs. The formidable total directs us to inquire as to the proportions in weight required, firstly for the pilotage navigation and " running " of the machine itself, secondly for defence purposes.

Obviously if it is possible by careful training to combine the various functions of the crew, a considerable saving in personnel might be effected; on the other hand, it is necessary in this case to study the " endurance " of the crew, since for very long periods at high altitudes it is necessary to provide " reliefs " for essential duties.

A " war " crew must clearly be selected after consideration of the offensive and defensive functions of the machine, and this will impose, therefore, a definite *minimum* limit on the number required. For purely offensive bombing purposes two men would be sufficient to work any machine, that is to say, one pilot and " one bomb-dropper "—any other members of the crew so far as the actual bomb-dropping is concerned would be unemployed. If then, two pilots are selected for a giant machine—both being, in addition, trained as " observers," navigators and bomb-droppers—these two men are sufficient crew to carry out all the necessary duties in connection with navigation, observation, and attack. It remains to decide upon the number of men required for " defensive " purposes and for duty as mechanics in connection with the engines, etc. These mechanics trained in addition as machine gunners should be able to fulfil all such functions in any

machine with not more than four motors. It is even possible that this number is too high except for very long range flights; in any case it is difficult to justify the inclusion of more than five properly-trained men in any giant machine so far built.

It is quite clear, however, that the crews of "giant" machines must be thoroughly trained and able to undertake a far larger range of duties than is required of aeroplane personnel employed on ordinary small machines.

Section (*b*), Bombs, Armament.

It is unnecessary to refer at length to the question of bomb armament, or any special bomb-dropping mechanism. The German giant machines show, however, a sharp divergence from Entente practice both in the quantity of bombs carried and in the method of carrying them.

The main offensive armament of German giants consisted of two or three very large bombs. A certain number of very small bombs were also carried, but these are of very secondary importance as regards the main functions of the machine.

Whatever may be the military advantage or disadvantage of concentrating the total weight of explosives in a very small number of bombs, there is no doubt that the adoption of this principle facilitates very considerably the arrangements for the storage and the carrying of the "bomb load." Not only is the weight of the bomb-carriers, release gears, etc., very much reduced by having only two or three bombs instead of ten or twelve, but the space required for storage is also very much smaller.

Whereas it is necessary when carrying a large number of bombs that the designer make careful and elaborate provision for their storage—perhaps to the disadvantage of some other requirement—in the case of two of these large bombs, the problem is very much simpler. Added to this it is, generally speaking, quite easy to arrange for the carriage of two or three bombs in a horizontal position, while in the case of a large number of bombs it is commonly necessary to adopt a "vertical" method of storage—with all the attendant disadvantages.

In respect of bomb-carrying equipment and storage, there is a good deal to be said in favour of the German practice, a circumstance which must be reflected in either a saving in weight or a saving in head resistance, as also in a lesser complication.

Section (*c*), "Maintenance."

The German giant aeroplanes, which, as we pointed out in the introduction, were primarily intended for strategic purposes, possessed, in consequence, several unsatisfactory and undesirable features. Generally speaking, the practical aspects of "maintenance" were almost totally disregarded. The time required to effect the changing of an engine is given as five to three days, a period which must be regarded as insupportably long. No special facilities exist for the rapid changing of wings, under-carriages, wheels, etc. The larger machines, particularly, may be said to be quite exceptionally impracticable as regards the elementary military requirements in relation to what we may refer to generally as "maintenance in the field."

It is to some extent true that these same faults are to be found in almost all giant machines, whether of German or Allied origin. In the case of German machines it may, however, be confidently asserted that the lack of attention to these important details very largely prejudiced the use and value of all existing giant machines.

(4) POWER PLANT AND INSTALLATIONS.

Section *(a)*, General Arrangement.

The horse-power required for giant machines being very much in excess of anything which can be obtained from a single engine unit, the designer is forced to adopt some arrangement which will accommodate a sufficient *number* of motors to provide the required total horse-power.

The problem of motor arrangement in giant machines may almost be said to be the principal consideration of the designer, who up to now has been confronted with the problem of how best to dispose the number of separate engine units which together make up the total power plant.

In so far as the range of horse-power obtainable from a single motor permits, it is obvious that there is nothing to be gained, except " reliability," from the adoption of more than a definite minimum number of engines. When, therefore, very large total horse-powers are required, the maximum horse-power of the individual motor is of very great importance. It is as well to recall here, as already noted in the introduction, that during the war Germany's designers had at their disposal only comparatively low-powered six-cylinder engines. This fact, then, is destined to have a very important bearing on engine arrangement and aeroplane design. (We have previously remarked that the revelopment of the V-type motor took place too late in Germany to be of service during the war.)

It will, perhaps, be best to consider first the question of engine arrangement as applicable in general to the three " Type " designs which we have discerned in German giant aircraft, since, apart from other details, it is obvious that the question of motor arrangement must exercise a profound influence on each design, and that all such arrangements must necessarily be dependent on the unit horse-power of the individual motor. For the German giant machine, up to the close of the war, the maximum horse-power available in a single unit did not exceed 300, and, generally speaking, may be taken at even less than this figure.

Motor Arrangement in " Type A " Machines.—Refer to Figs. (*a*) to (*g*) for " Type A."

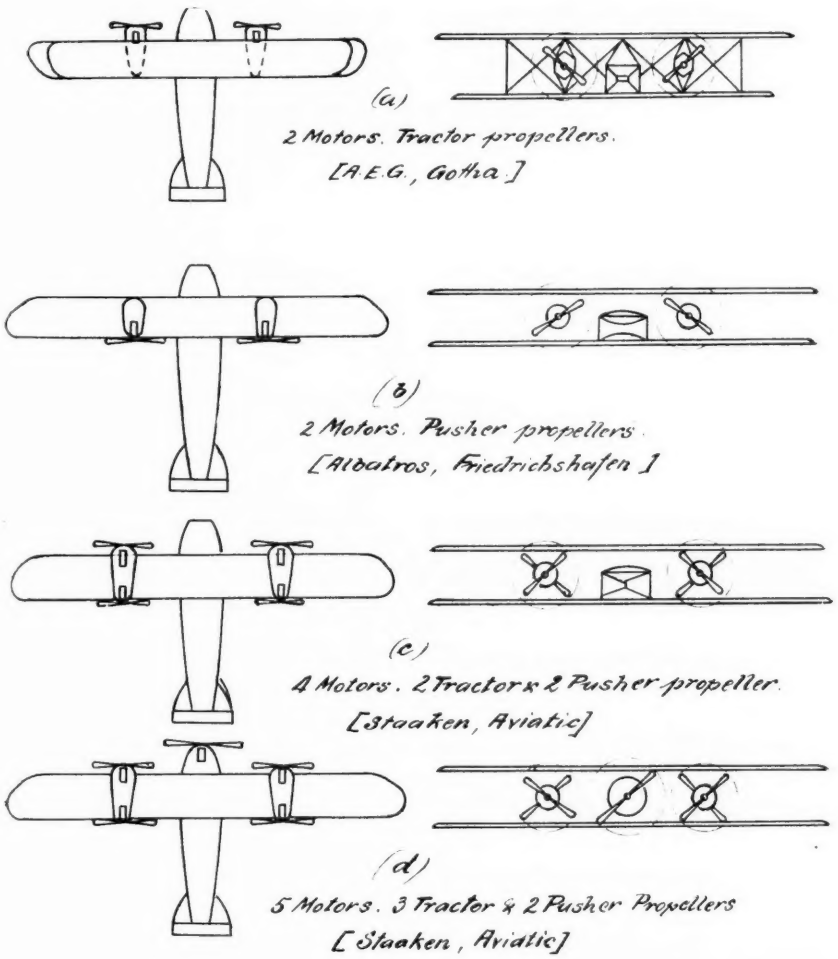
The sketch diagrams (*a*) and (*b*) represent the first stages in the development of the giant " Type A " machine. These designs are well-known, and there is no doubt that this two-motor arrangement is a simple and satisfactory compromise *within* the limits of horse-power which the use of two motors permits. In the case of Germany this limit was a low one, and may be put at a maximum of 600 h.p. It follows that other arrangements had naturally to be adopted in order to permit designs to increase still further the total horse-power (and hence the useful load).

The next step in development is illustrated in Fig. (*c*); it is a combination of Figs. (*a*) and (*b*), and has the advantage that it permits of the total horse-power being doubled with only a slight increase in head resistance. This arrangement has, however, the obvious disadvantage that the rear propellers are working in the " slip-stream " of the front propellers, and are consequently inefficient. The compromise is, nevertheless, in many respects a good one, since it introduces no unnecessary complications. The same simple method of construction can be used, and the arrangement retains the good points of the " Type A " weight distribution. Moreover, in this particular case the engine nacelles become sufficiently " roomy " to accommodate a mechanic between the two engines, and it is possible, therefore, to claim that the engines are accessible during flight.

Fig. (*d*) illustrates the next step in the effort to apply still more horse-power to a single machine. In his case, however, we find that the five-engine design (Fig. (*d*)) *preceded* the construction of the latest type four-engined (Fig. (*g*)) machine. This circumstance is yet another indication of the unfortunate circumstances in which German designers found themselves in regard to the available horse-power from a single motor unit. The point is one of peculiar interest, as it shows that the five-engined design was abandoned in favour of the four-engined

system *so soon* as a slightly more powerful motor made its appearance, and thus allowed of a four-engined group to develop more power than had previously been available with *five* motors. It is only necessary, however, to remark that the presence of the fifth motor (Fig. (*d*)) was also undesirable from a military point of view as interfering with the " view " of pilot and passenger.

Sketch diagrams illustrating the Engine Arrangement in "Type A" machines.

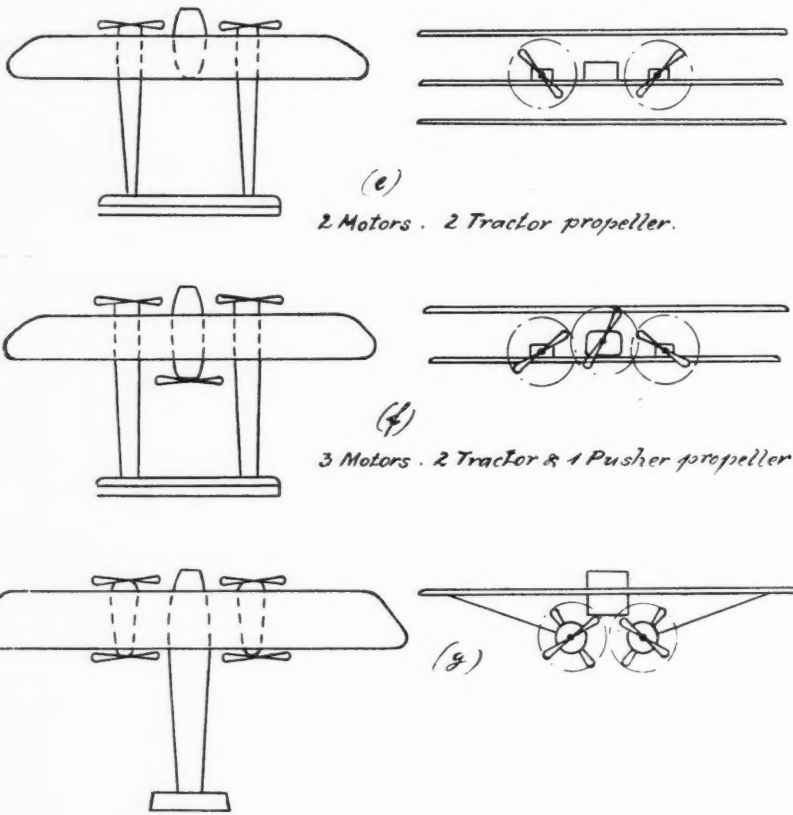


Figs. (*e*) and (*f*) illustrate yet another variation of motor arrangement within the " Type A " designs. This system, originally developed by Caproni, has never been very satisfactory, and is not adapted to the employment of more than three motors. The design, therefore, seeing that the development of giant machines has

been contingent on the available *total* horse-power, could only serve as a " stop-gap," and is incapable of development.

Fig. (*g*) illustrates yet another variation of motor disposition. This design, originally intended for aeroplanes, has only been developed in seaplanes, and is for our immediate purpose of no great consequence. The motor arrangement is identical with that of the previous four-engined types, and the disposition differs only in relation to the planes.

In none of the foregoing arrangements is there any difficulty, so far as the



motors themselves are concerned, in the matter of engine installation. Neither does the adoption of any of these motor dispositions introduce special complications or difficulties in the design or construction of engine beams, tanks, controls, connection, etc. From this point of view, then, the question of arrangement, design and construction of the " Type A " power plant installation is simple and satisfactory.

We have shown in the previous chapter how German designers were driven to abandon " Type A " designs for " Type B " in an endeavour to increase efficiency and at the same time to augment the available horse-power. It must now be pointed out that the question of engine arrangement (which was primarily

responsible for this departure) was also contingent on the question of *propeller* arrangement; these two points are indeed inseparable. In the case of the land aeroplane the designer has a wide choice of propeller positions, but on the other hand the seaplane designer has to give considerably more attention to this matter on account of the danger to propellers from spray and waves. Certain variations in motor disposition are to be expected, then, as between the giant aeroplane and seaplane. This point is of no particular importance for our purpose, but is mentioned in order that any novel arrangement in seaplane motor positions may not serve to distract one from the main circumstances.

The question of " gearing " will be treated later, in Section (*b*). It will suffice for the moment to say that in the case of " Type A " designs the introduction of gearing may be regarded as an accessory circumstance which in no way affects the actual design or execution of the machine.

General Remarks on " Type A " Engines and Installation.

All through the " Type A " designs a general simplicity in the engine installation is to be remarked. There is no unnecessary complication, the various component parts of the whole power transmission are fairly widely separated and readily accessible when on the ground, if not in flight. The whole of the fuselage is left clear for crew, armament and *fuel*.

Engine or Motor Arrangement in " Type B " Machines.—Refer to Figs. (*a*), (*b*), (*c*) and (*d*) for " Type B."

In the case of " Type B " designs, the sequence of development is again fairly clear. The first arrangement to appear in a concrete form is illustrated in Fig. (*b*) (four engines with four wing propellers). This design was shortly followed by the Fig. (*c*) disposition, which is indeed the same arrangement, except that six engines are used instead of four.

Fig. (*d*) illustrates a still more recent development. As before, the sequence of production has a certain significance, and must not be overlooked. Fig. (*a*) represents a late development of the (*b*) and (*c*) arrangement, which was apparently never seriously taken up, but probably represents an attempt at high speed and long endurance. The machine is, of course, considerably smaller than its prototypes.

To revert to the Fig. (*b*) four-motor, four-propeller design, we find here the first attempt to realise " accessibility " for the motors, and in conjunction with this an improved " performance," due to reduced head resistance. It is also necessary to remark that with this motor arrangement the designer is able, by utilising suitable transmission gears, to so dispose his propellers that their disc areas do not overlap. This feature is, of course, a distinct advantage over the back-to-back motor disposition which we find in the four-engined " Type A " machines.

So far, then, as the general efficiency of the propelling units is concerned, this arrangement should give a very much higher figure of efficiency than has hitherto been possible. If, then, the gearing and transmission systems prove to be satisfactory, the general design and disposition of the power plant installation on these lines would appear to be almost ideal. We are not, however, for the present concerned with the gearing, which introduces its own special problems. It must, however, be remarked that in spite of its many apparent advantages, the actual and practical installation of the motors in a necessarily somewhat confined space, is not altogether satisfactory. Indeed the whole installation becomes so cramped that " accessibility " becomes, perhaps, a more theoretical than practical advantage. Nevertheless, it is impossible to deny a certain advantage in regard to " maintenance," protection from weather, etc., which this system

possesses. It is quite obvious, however, that the adoption of so much gearing and special transmission shafting introduces very real mechanical difficulties, and calls for far more technical skill, even in the mere routine of " maintenance," than in any other type yet considered. This gearing, moreover, adds considerably to the weight of the power units; but as we have already remarked, this must be opposed by the possibility of a largely increased " efficiency."

Demands for a further increase of power in the case of this design are met (Fig. (*c*)) by the addition of another two motors coupled up through the same system of gearing, and an identical propeller disposition. The only real difference, therefore, between types Fig. (*b*) and Fig. (*c*) is in the detail arrangement of gears and transmission. The whole installation becomes, however, still more complicated, and the need for expert mechanics to operate the necessary clutches and other accessories is clearly apparent.

Fig. (*d*) illustrates another variation of the same arrangement, differing principally in the matter of propeller disposition, and possibly offering, on account of the comparative simplicity of the gearing and transmission, a more practical solution of the problem. The relative efficiency of the single and four-propeller arrangement is a matter of simple calculation. In any case a considerable reduction in the weight of gearing and transmission shafting is to be reckoned on. At the same time the practical military disadvantages of the large tractor propeller—in front of a fuselage already too large to permit of good observation—are very real.

The installation of the motors and gears is in this case again very cramped, though the advantage of " accessibility " and general protection from weather remains.

General Remarks on the Engine Installation of " Type B " Machines.

In considering the engine installation of these various " Type B " designs, it is impossible to avoid being unfavourably impressed by the complications and congestion which the massing together of the motors in the fuselage entails. It is difficult at first sight to account for this feature in what is fundamentally a quite simple arrangement. The effect, however, is not surprising when it is remembered that in addition to the motors themselves it is necessary to find accommodation in the fuselage for the crew, transmission shafts and gearing, with the necessary clutches, armament, bombs and *fuel*. In addition to which must be reckoned the further complication of concentrated engine controls, fuel piping, etc., etc. Moreover, it is impossible to dispense with any of these items, and even the petrol tanks cannot be excluded from the fuselage, since there is no room *inside* the wings, and to place them *between* the wings would only set up additional passive head resistance (at the suppression of which the design is aimed).

The engine bearers, which must in any case be specially strengthened to take the concentrated weights of the engines and gears, have to be made even stronger than one might anticipate, owing to the well-known fact that a number of separate engines running on the same bearers or platform demand a far greater degree of rigidity than is normally required for one engine.

All these factors conspire, therefore, to multiply complications and with this to add very considerably to the structural weight of the fuselage. So that even if the increased efficiency obtainable from the choice of propeller disposition, propeller revolutions, and the suppression of head resistance, is more than sufficient to counterbalance the weight of gearing and transmission shafts, there is still a very considerable additional fuselage structure weight to be compensated for.

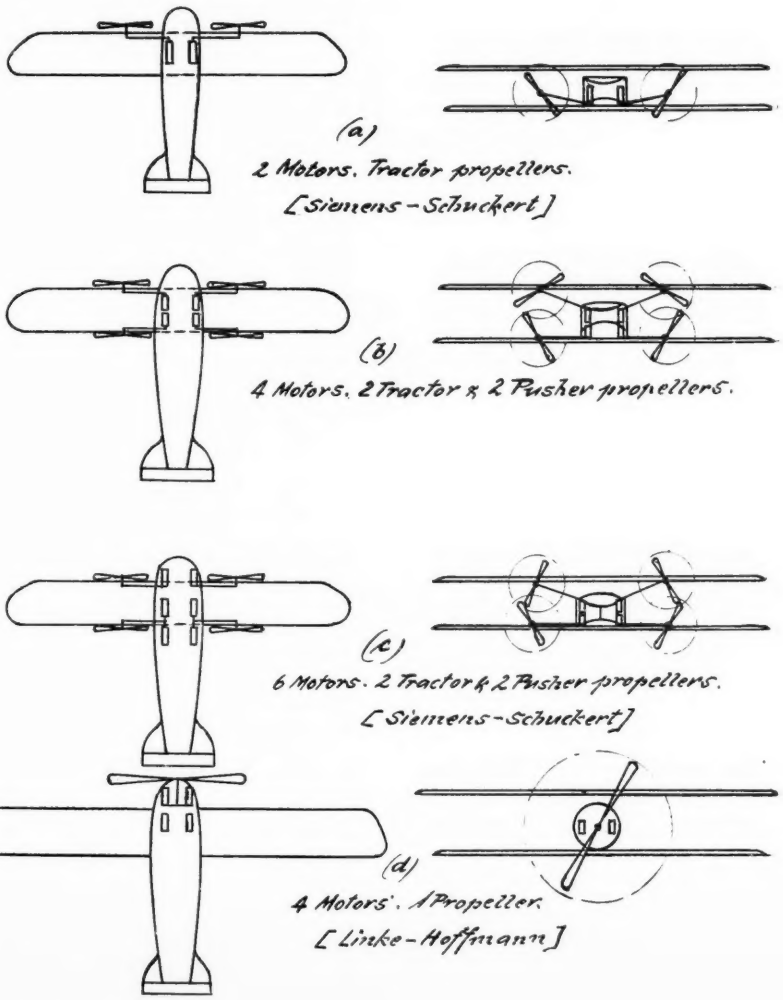
Moreover, the possibility of employing the motor arrangements in the " Type B " designs is entirely dependent on the provision of suitable and satisfactory

gearing; and the motors themselves must in this case take second place in importance to the gears and transmission.

In practice, the installation of these multi-engined groups, their gears, clutches and shafting, is by no means a simple matter. The mechanical difficulties are considerable and the arrangement has the further disadvantage of complication within a confined space. In addition to which the mechanics or engineers carried in the machine must be very highly skilled.

④ Power-plant and installation. Section (A)

Sketch Diagrams illustrating the Engine Arrangement in "Type B" machines.



Arrangement of Power Plant in "Type C" Design.—See Figs. (*a*), (*b*), for "Type C" designs.

The installation of the motor in the single-engined "Type C" machine, illustrated in Fig. (*a*), is so simple as to need no comment. It is only necessary to draw attention to the disposition of the fuel tanks of which we shall have more to say in Section (C) of this same chapter.

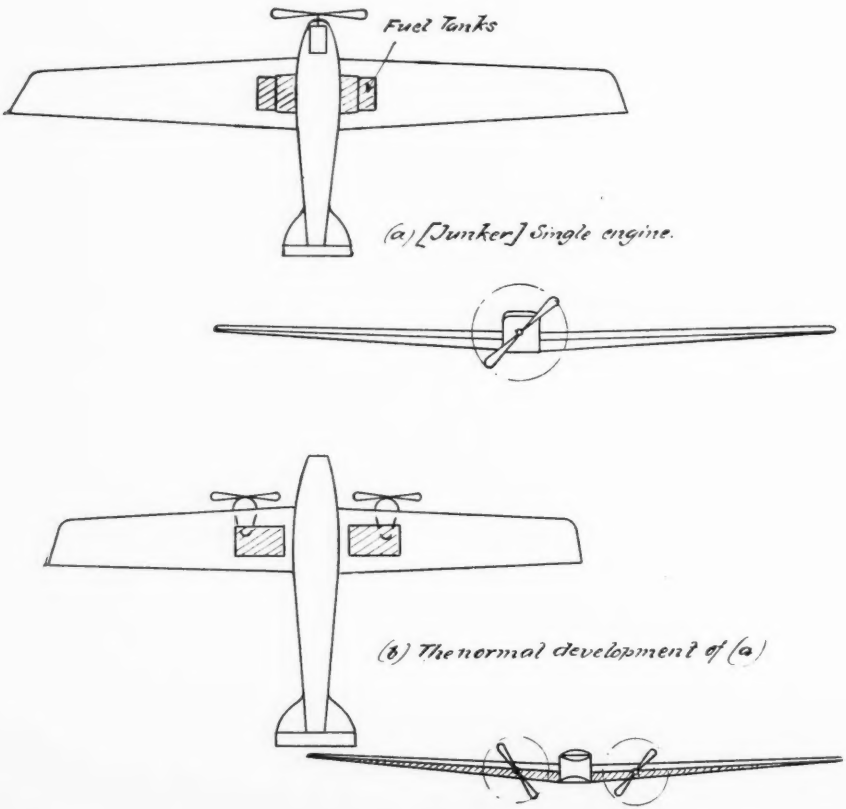
Fig. (*b*) illustrates an imaginary development—which is already conceived in the mind of Professor Junkers—and to which we shall have occasion to refer in our conclusions.

In both these cases we note a complete simplicity in engine installation, comparable with that existing in the "Type A" designs.

Section (*b*), Gears and Gear Drives.

As is well known, an air propeller develops its maximum efficiency at about

Sketch Diagram illustrating Engine Arrangement in 'Type C' machine



900 revolutions per minute. This speed is considerably less than the normal crankshaft revolutions of an aeroplane motor, and it is possible, therefore, to increase the efficiency of the propelling units by introducing gearing between the crankshaft and the propeller. Hence the reason for the adoption of "reduction gearing."

In Entente countries the development of the high speed V-type motor was accompanied in the majority of cases by the introduction within the engine unit itself of a reduction gear. In every case the reduction gear formed a definite part of the engine, and was incorporated in the same lubrication system, etc.

In Germany, however, owing to the fact that the standard six-cylinder stationary motor had a much lower crankshaft speed than the Entente V-type motor, the necessity for reduction gears was very much less marked, and indeed quite unnecessary except for the comparatively slow giant machines. We find, therefore, that while the existing German giant machines are fitted with reduction gears, the gears themselves are separate units in regard to the motors. This circumstance entails the use of larger and stronger engine bearers than would otherwise be necessary, besides introducing other complications such as the provision of special lubricating systems.

The main fact which we must bear in mind, however, is that the "*reduction*" gears found in German giant machines are fundamentally the same development as we are already acquainted with in the Entente V-type motors. In the case of the German giant machines the actual ratio of reduction is, of course, calculated for the particular machine to which it is designed, whereas in the case of Entente "engine gears" the gear ratio is a compromise.

It has been necessary to make this general comparison before considering the actual arrangement of the German gear and gear drives, in order that we shall not be misled into thinking that these gears are a novel departure in aeroplane practice. Actually the system is well known and extensively used in Entente countries, where, however, the whole arrangement is enormously simplified (if not so efficient), and where we require no additional lubricating systems and no oil-cooling radiators. It is important, before proceeding further with this particular inquiry, to remember that the "reduction gears," though they may be combined with gear-driven transmission systems, must be considered separately and quite apart from the transmission systems which we shall find in the "Type B" machines.

Gears in "Type A" Machines.

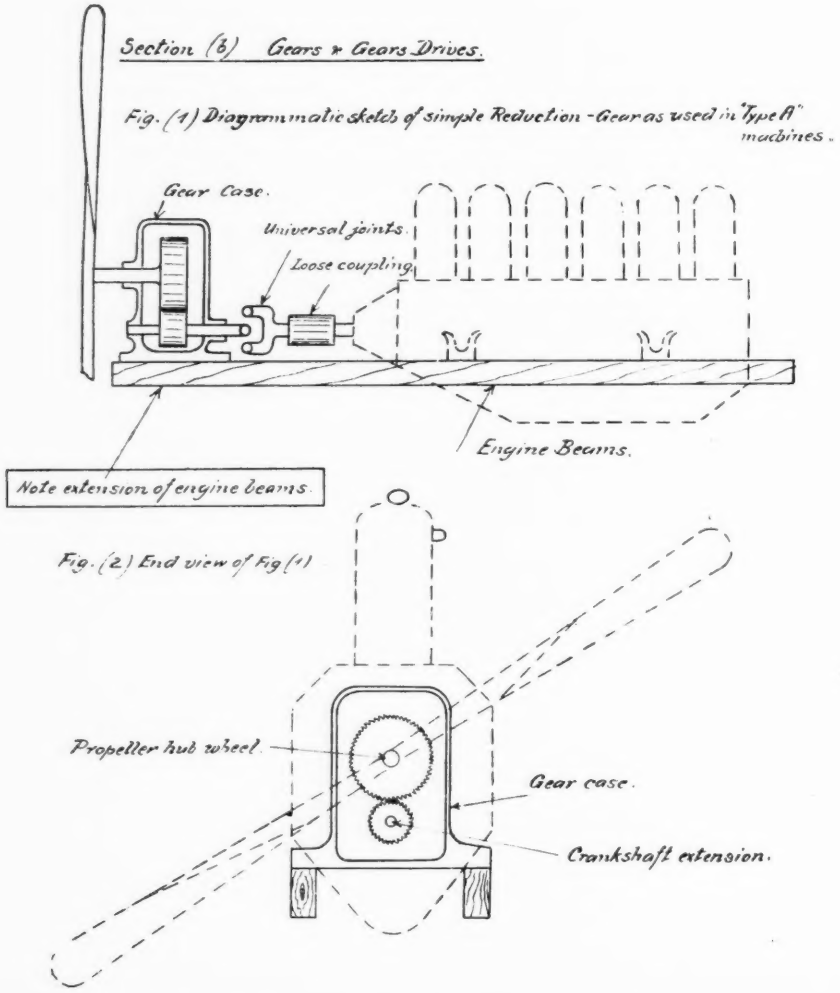
Figs. 1 and 2 illustrate the general arrangement of the type of gear in use on the "Type A" giant machines. The arrangement, as can be seen at a glance, is quite simple, but involves the employment of much longer and heavier engine bearers than would normally be required, and further necessitates the fitting of a universal joint and loose coupling between engine and gear box. In addition to this the gear boxes require a special lubricating system with their own oil-cooling radiators, oil reservoirs, "sight" thermometers, etc. All these details are redundant to the ordinary reduction gear arrangement as fitted in the Entente V-type motors.

As we have already remarked in a previous paragraph, the great advantage of this system is that the reduction gears are specially designed for each individual machine. Naturally, where large horse-powers are concerned, any increase in the propeller efficiency, due to a careful choice of propeller revolutions, must result in a very large gain in useful load. Indeed, a gain of from 10 to 15 per cent. may be expected from the use of carefully chosen gearing over results with a direct driver propeller. Undoubtedly the "Type A" giant German machines owe a great deal of their success to the selection of suitable gearing. It should be added

that the use of these gears, although attended by success, has not been entirely free from small practical difficulties.

Typical Gears and Gear Drivers in "Type B" Machines.—Refer to Figs. 3, 4 and 5.

The gears and transmission systems with their necessary bevel drives serve the dual function of, firstly, acting as "reduction gears" in order to transform


Section (6) Gears & Gears Drives.
Fig. (1) Diagrammatic Sketch of simple Reduction-Gear as used in "Type B" machines.
Gear Case.
Universal joints.
Loose coupling.
Engine Beams.
Note extension of engine beams.
Fig. (2) End view of Fig (1)
Propeller hub wheel.
Gear case.
Crankshaft extension.

the engine crankshaft revolutions to a suitable propeller speed; and secondly, of transmitting the necessary power from the engines in the fuselage to the propeller itself. As for each propeller, a minimum of two bevel drives are necessary (one

at the engine and one at the propeller shaft), the reduction in the speed of revolution can be made either gradually or in a single train of gear wheels. As a rule it is more convenient to do this gradually by using the bevel drives as "reduction gears" also.

Figs. 3 and 4 illustrate a typical arrangement of gear drive in a "Type B" machine. It is not necessary to investigate the details of the gear box construction or mountings. It is sufficient to say that the gear box itself is principally a "power distributor" which is also arranged to contain one of the necessary bevel drives and to act as "reduction gear."

Reference to Fig. 4, which outlines the arrangement of a six-engined, four-propeller group, will show that besides the six engines the machinery or mechanical plant includes four gear boxes (bevel type), four (propeller) bevel drives, fourteen universal joints and six clutches, in addition to which there is a considerable quantity of shafting. With this elaborate equipment of mechanical plant, one secures, however, the following advantages. Any one motor can be de-clutched and isolated for purposes of repair or if not required. The transmission shafting can be arranged as required to drive the propellers in positions such that their "disc" areas do not overlap. The propeller revolutions can be arranged for maximum efficiency.

As to whether or not the advantages, from a mechanical point of view, are sufficient to counterbalance the very considerable complications which such gearing entails is a matter open to the gravest doubt. It is certain that so far as German experience goes the results obtained have not been entirely successful. The design of the mechanical parts is difficult, the extra weight involved is considerable, and the work of maintenance and adjustment both intricate and delicate.

In effect, from a practical and particularly from a military point of view, complication of this description is best avoided. In any case it is only justifiable if the advantages to be gained are of a more substantial character than is traceable in the machines we have under review.

Gears and Transmission Systems in "Type B" Machines.

Fig. 5 illustrates the gear drive arrangement as fitted to the single propeller "B type" giant (see Fig. (*d*), aeroplane types), as in the other examples of the same type we find a similar complication, though in this particular case the general "lay out" of the gearing and clutches is at first sight slightly more simple.

In practice the congestion and complication which distinguish all these arrangements is clearly apparent and the same difficulties with the engine bearers and gear box details are to be found.

The first set of gears to be tried have not given satisfaction. Nevertheless, it is possible that a reliable gear of this type could be evolved with very little further experiment. In any case the whole arrangement, so far as mechanical difficulties are concerned, is both superior to and simpler than the gearing and transmission system when the propellers are in the wings.

General Remarks on Engine Arrangement in "Giant" Machines.

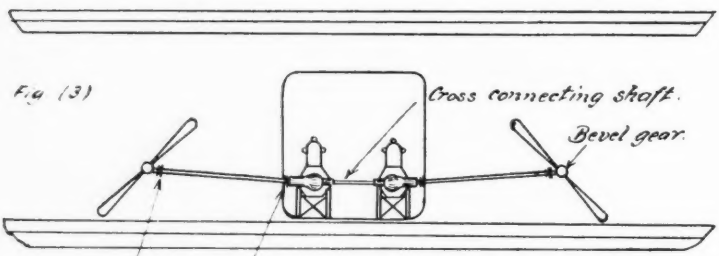
As regards the future trend of events in relation to "engine arrangement," we distinguish three separate and vital factors which must inevitably govern all other considerations: (*a*) Within limits which cannot yet be defined, the best military "giant" machine will undoubtedly require the maximum possible total horse-power. (*b*) The total horse-power of a giant machine should not be made up of a large number of separate engine units. (*c*) Maximum possible horse-power in a single engine unit is essential to success in giant aircraft.

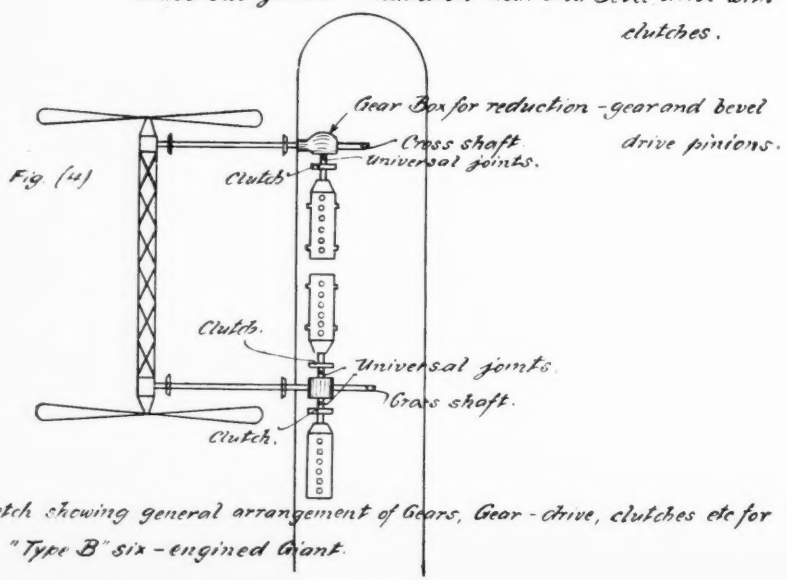
German experience has clearly shown, as indeed was only to be expected, that complication is perhaps the worst enemy of practical efficiency.

It is inconceivable that the German six-engined "Type B" machines could have been designed or built, if it had been possible to obtain the same total horse-power with a lesser number of motors. The presence of six motors in a single machine is traceable to the low unit horse-power of the available German aeroplane engines, and must be considered as accidental or incidental to considerations of "reliability."

Nevertheless, there is no question that larger and more powerful engine units will most probably assure the temporary continuancy of not only "Type A"

Typical "Type B" machine, Gears and Transmission System.



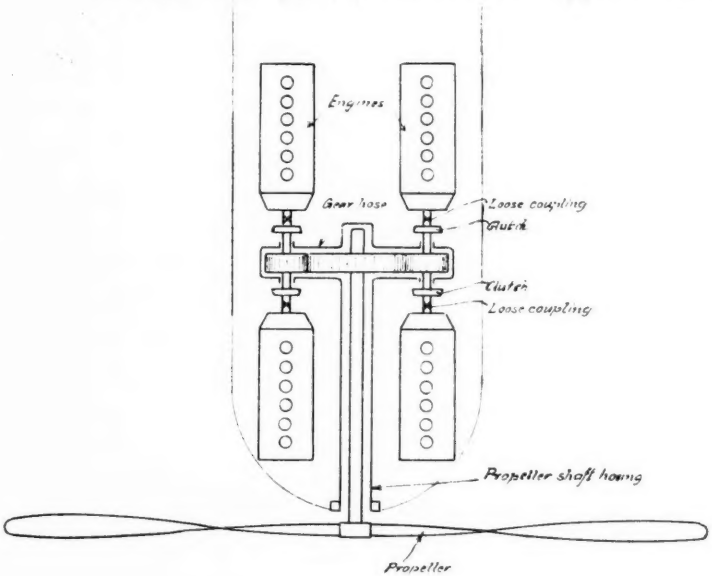


Sketch showing general arrangement of Gears, Gear-drive, clutches etc for in "Type B" six-engined Giant.

but possibly also "Type B" machines. This is indeed certain to be the case when we consider that not only will larger and more powerful engine units permit of the building of larger "giant" machines, but will also allow us to carry more load in a smaller machine. In this way, were it possible to obtain double the horse-power from a single engine than is now the case, one would undoubtedly revert to the twin-engine designs as a preliminary step before again employing a larger number of motors. It is in fact certain that should engine development continue—as there is reason to suppose it will—and should a single engine of 1,000 or 1,500 h.p. become available, then we may rely upon obtaining a better performance with a two-engine design of whatever type than is at present possible with four or six motors. Such a machine would moreover be simpler in every way than the larger giants of to-day, and in consequence of a far greater military value.

Reduction gears & Gear drives in "Type B" machines.

Fig. (5) — diagrammatic sketch of gearing & Drive for 4 engined single propeller Type B giant, (see fig (4) for Type B aeroplanes) [Linke-Hoffmann]



It may be objected that such a proposal would sacrifice such "reliability" as the present day designers may claim. The value of this "reliability" in relation to military wants must first of all be examined. If we assume, as indeed must be the case, that giant "military" aircraft leave the ground *when carrying their war load*, with a certain definite "speed of climb," we get some indication of the relative horse-power available in excess of that required for "flying level." To assure *absolute* "reliability," then one must so arrange the power plant that no ordinary accident or circumstance can rob the machine of more power than is required for "climbing" only. With the present state of development in aeroplane motors this cannot be said to be within the realms of possibility, even

if the total horse-power be subdivided amongst several motors. A partial reliability can however be obtained by a sub-division of the power plant, and this is present to a greater or lesser degree in the various examples of German giant aeroplanes.

It is already quite clear that the smaller the number of motors—and consequently the less the complication—so much the better from a purely military point of view. What then is the best compromise, in regard to the selection of the number of motors to be fitted? Efficiency points to the minimum possible numbers required to supply the necessary horse-power. "Reliability" demands the maximum sub-division of the power plant. Military requirements embrace, efficiency, "reliability" and simplicity. The choice must in consequence depend primarily on the military requirements, which in themselves demand a compromise. It remains to decide on the smallest maximum number of motors which such "reliability" as we are justified in demanding from military machines should dictate.

Obviously there is no possible object in demanding a greater sub-division of the power plant than would allow of the machine under any ordinary circumstances of average mechanical failure from returning safely to its base. In a military machine this means that no average mechanical failure would prevent the machine from returning (at a necessarily reduced speed) over a distance representing its maximum radius of action, without its bombs and without unnecessary fuel. Such circumstances would allow of the saving of the machine and also the crew under any and every circumstance, at the trifling cost of jettisoning both bombs and surplus fuel. Briefly, a military giant machine should be able to fly with approximately half its fuel load and with no bombs when under reduced power resulting from the worst possible circumstance of normal mechanical derangement. In a giant military aeroplane the necessary sub-division of the power plant under these conditions is happily comparatively small.

Under no circumstances are designers justified in departing from this criterion of a least maximum number of motors, except where it is impossible to obtain the required total horse-power without exceeding the least maximum desirable number of separate motors. In any case, as we have elsewhere remarked, *real* "reliability" is not to be sought in the number of separate motors, but in the improvement of the individual aeroplane motor itself.

Propeller Arrangement.

Perhaps the greatest potential advantage of the "gear and shaft drive" transmission system lies in the range of choice as to propeller "arrangement," irrespective of the placing of the engine. This particular feature may be of value either from a structural point of view or on account of military requirement in connection of "arcs of fire" for guns.

It is doubtful if in practice either of these advantages will be realised without a correspondingly heavy sacrifice in some other direction. In any case existing German "shaft drive" designs cannot be said to confer any military advantage to examples of machines so fitted; neither has the introduction of shaft drives facilitated or improved construction.

As regards the general arrangement of propeller positions and numbers of propellers in giant machines, there is but little to remark on, except in the case of the "Type B" machines.

The number of engines has in the majority of cases been the deciding factor in the selection of the number of propellers, irrespective of the possibilities of variation which the use of "shaft drives" permit of in all the "Type B" machines—not excepting the case of the most modern engined, single propeller design—the number of propellers has been decided by convenience in the matter of providing shaft transmission.

In effect the whole problem has up to the present been governed by the circumstances in relation to the individual aeroplane engine. Its ultimate improvement is dependent—as indeed is the whole future of the giant machine—on the development of the aeroplane motor, which in time must ultimately decide the number of motors to be fitted in a single machine.

While the disposition of the propellers in multi-engined giants is a factor of considerable importance in relation to efficiency, experience has shown that the distribution of the individual propeller centres away from the "centre of thrust" of the machine is attended by many disadvantages. This is particularly the case when the individual propeller centres are not situated (as in some of the "Type B" machines) on the same horizontal plane as the "centre of thrust." In this case the handling of the machine, particularly when landing, becomes much more difficult, while any variation in the power of an individual motor must be compensated for by both the longitudinal and directional controls.

Section (*c*), Fuel Storage.

There is nothing very important to remark concerning the detail arrangements for storing fuel in German giant machines except that as a general rule a large number of small tanks are fitted, as distinct from one large tank with many sub-divisions. Also the weight of the tanks is, generally speaking, proportionately very much less than in Allied countries, because in the majority of cases aluminium is employed instead of tinfoil or brass. These are, however, unimportant details.

It is extremely important for our purpose that the *disposition* of the fuel tanks, as affecting the weight distribution in the machine, should be carefully considered. More especially, as the better the machine, the greater will be the proportion of fuel weight. (It is true that this question is dependent on the proportion of *useful* load allocated to military load, but at the same time a long *range* necessitates a high proportion of the same useful load being allotted to fuel weight.)

It is necessary to consider, therefore, what influence on the general design of giant machines the question of fuel storage actually has. If we consider the weight of the power plant (motors, propellers, etc.) and the weight of the fuel (and tanks) as two separate portions of a single "disposable" weight, then it is quite clear that since neither of the two portions can be dispensed with, the *disposition* of the one must bear a distinct influence on the disposition of the other, if a satisfactory weight distribution is to be maintained. And as these "weights" possess a certain irreducible "bulk," it is clearly not possible on account of head resistance to distribute them haphazard in the machine.

As weight distribution has a direct bearing on the construction, and particularly on the maximum limits of construction, it is obvious that a certain satisfactory medium must exist between the ideal but impracticable limit of equally distributed weight all along the wings and the equally unsatisfactory concentration of weights in the centre of the machine. Herein lies the whole importance of this question of fuel distribution, since apart from head resistance the fuel is the most easily disposable weight portion in the whole machine.

"Type A" designs, whose distinguishing feature is the distribution of motors in the wings, naturally have their fuel tanks in the central fuselage where there is ample room and where—as the fuselage is an essential part of the machine—they create no extra head resistance.

In "Type B" (engines in the centre) the fuel tanks are still to be found in the fuselage; but in this case their presence is very undesirable, firstly, on account of the lack of space and consequent complication; secondly, because the weights are already too centralised.

"Type C" designs (cantilever wings) show the first realisation of this fuel difficulty. Professor Junker places his tanks *inside* the cantilever wings. Where this is possible it is clearly a simple matter to arrange (without increasing head resistance) the weight distribution in any manner desired. It is to this point attention must, so far as fuel installation is concerned, be specially directed.

Section (*d*). Note on Use of "Forced Induction."

A good deal of attention had been directed in Germany to the question of "forced induction," the importance of which in relation to giant aircraft appears to be fully realised. Valuable experimental data on this subject is to be found in the "Technische Bericht." The details of the forced induction plant need not here be described. The principle, which is that of applying (when at high altitudes) air under pressure to the carburettors of the aeroplane motors, is well known and needs no explanation.

It has been successfully put in practice in the case of a German "Type A" machine (four motors of 200 h.p. each) by the installation of an additional 120 h.p. motor, driving a turbine "blower" which supplies air under pressure to the four aeroplane motors (and also to its own motor), by means of a common piping system. This machine, which, without the "blower" forced induction installation, has a ceiling (under normal load) of about 7,000ft., has actually reached an altitude of over 20,000ft. when using the "blower." The turbine "blower" and engine are heavy, but the results are without doubt most remarkable. No information as to the "life" of the motors under these conditions of higher working load is available. The conditions as regards the "life" of the motors under these circumstances would be analogous to using the engines continually at full power on ground level. The majority of Entente aeroplane engines would not stand this treatment. Unfortunately no information is available as to the effect on *range* caused by the use of the "blower." It is possible, however, in spite of the extra petrol consumption of the aeroplane motors (also of the "blower" engine) that due to the increased speed obtainable at high altitudes a considerably greater range might be attainable.

The whole matter is of very great importance to the future of giant aircraft, but the information at present available does not permit us to go beyond this statement.

There is yet another alternative by which this power of the motors can be maintained at high altitudes. The system involves designing the motor with a super (high) compression ratio, such that the throttle must not be fully opened until the machine reaches a certain altitude. This arrangement involves fitting some mechanics by which the throttle opening, or the fuel supply, can be automatically restrained until a certain minimum altitude is reached. This very necessary safeguard is most easily arranged for by means of a fuel pump which takes the place of the gravity tank. This arrangement is far preferable to the "blower" system as involving less mechanical gear.

IV.

CONCLUSIONS AND DEDUCTIONS FROM PAST EXPERIENCE.

In Part II. of this review we divided the examples of German giant aeroplanes into three separate classes, which we have referred to as "Type A," "Type B" and "Type C." Within these three separate types we were able to distinguish the various characteristic features of each group of machines, and from these characteristics to assess the future value of each "type" of design.

In Part III. we have examined the practical aspect of the various minor features of all the machines under review. This examination has revealed the

far-reaching effects of the fundamental circumstances which we had previously outlined in the introduction, and has at the same time accounted for the various departures from the normal standard practice in Entente countries.

We are now enabled, therefore, to obtain a clear and more comprehensive view of the whole subject, and to form some opinions as to the possibilities of future developments. More particularly are we able to adjust our preliminary conclusions as to the value of the Types "A," "B," "C," in accordance with the lessons of practical war experience.

Before proceeding any further with our main conclusions it is desirable perhaps to re-state the real objective aimed at in the development of giant aeroplanes. This is simply and entirely that of increasing the *useful load*.

An increased useful load can be reflected in a variety of ways, such as bomb carrying capacity, greater radius of action, etc. In any case the augmentation of the useful load is in itself a fundamental military advantage for all offensive purposes. Giant machines are therefore essential to every State or Government whose prestige and position depend upon military guarantees.

The unique advantage of the giant machine lies in the fact that its large useful load permits it to operate over great distances and to carry a very heavy load of bombs, with a minimum of effort in so far as personnel and "maintenance" are concerned.

To consider the "giant" machine from any other than a military point of view would be for our purpose unprofitable, and our conclusions, therefore, will have no intended connection with the "commercial giant" of the future, nor are they concerned with "commercial economy."

The military giant machine must have not only a large useful load, but the *maximum possible* useful load. What we wish to discover then is the simplest and most satisfactory way of producing and maintaining such a machine.

Our examination of actual German "giant" machines has not revealed any one type or concrete example which is in its present state worthy of imitation, or suitable as the basis of departure for the development of the future "giant" machine. At the same time we can now clearly distinguish that "line of least resistance" which shall lead to the establishment of a future type, the conception of which shall be based on considerations both fundamentally sound and capable of practical fulfilment.

The Selection of "Types for Development."

"*Type A*" *Giants*.—German experience clearly shows that real efficiency cannot be obtained from designs of this nature. Actual practice supports in fact the preliminary conclusions which we drew up in Part II. for these machines. At present, however, and until the development of a more suitable type takes place, these machines possess military features of some value.

"*Type B*" *Giants*.—The military disadvantages, mainly due to complication, and the constructural difficulties which our examination of these machines has revealed, renders this "type" quite unfit for further development. It is doubtful if, in the light of actual experience, these machines will even have the temporary "commercial" vogue which we had previously anticipated.

In any case the existing examples cannot be considered as a satisfactory basis for development; are totally unfit for military purposes, and can only serve as a warning in the future.

"*Type C*" *Giants*.—Unfortunately we have not encountered any concrete examples of "Type C" *giants*. Sufficient information has, however, been available to show us that, for the present, the "cantilever wing" type of design has immeasurable possibilities.

Enough has been said in the previous pages of this review to emphasise the marvellous adaptability of this " type " of design to the various and detail requirements of " giant " machines.

The all-metal construction, which is perhaps the main and principal feature of the " Junker " conception, is of great military value in any class of machine. With a " giant " machine, for which the provision of hangars is in any case a great difficulty, it assumes an even greater importance.

For the present the best, and indeed the only satisfactory, basis for the development of " giant " machines is contained in the genesis of the " Junkers " cantilever wing design.

Though this type of machine has not yet appeared in " giant " form, we are however in possession of sufficient information in regard to the normal procedure of development (as exemplified in other designs), such as to render the process of development comparatively simple.

The realisation, execution, or construction of machines within the range of this primary and basic point of departure, must necessarily vary in matter in matters of minor detail. It remains to extract from previous experience with other types of design, the guiding principles in all such matters.

NOTE.—Professor Junkers, whose connection with aviation is derived solely from his conception of his design, has since been appointed as Technical Director of the German Civil " Air Ministry," an appointment which may be taken as a guarantee of the fact that the German Government have grasped the immense importance of this latest development. Already a number of German firms are imitating in the design of " civil " machines the conception and construction of Professor Junkers' machine. Professor Junkers himself has revealed the fact that his present machine is a forerunner only of the future.

Every satisfactory military aeroplane is a monument to successful compromise. In spite of a multitude of detail and technical improvements, German ingenuity failed to take sufficient account of this fundamental and elementary principle, the neglect of which is emphasised by the failure of their largest " giant " productions. For the future then, it is essential that the initial conception of our giant machines —the definite *functions* of which must first have been decided upon—must be evolved upon a basis of compromise. Every detail must be studied in advance, the military requirements being embodied in the design rather than, as is so often the case, being considered as accessory features following the evolution of the machine. The successful designer must avoid the hypnotic influence of precedent, the reactionary tendency to build in miniature, and the fatal influence of complication. He must distil the knowledge gained from the failure of previous types, and profit from the successes of every detail in design. Above all he must bring to bear on the question of design every item of experience and experiment which shall tend to facilitate the practical working and " maintenance " of the completed machine when operating in the field.

Construction. The Dimensions of Giant Machines.

The military giant machine is essentially, as we have already seen, that aeroplane which concentrates within itself the maximum " offensive power." From this criterion there can be no departure.

Unless therefore the whole principles of flight are radically altered our giant aeroplane will be the *largest existing machine of its period*. On purely theoretical grounds this fact can be disputed; in actual practice as supported by evidence from every quarter it admits of no contradiction.

In order to fulfil their military duties it is essential that " giant " machines should be able to operate under all conditions and be at the same time independent of aeroplane hangars, the provision of which is always inconvenient and often

impossible. For this reason metal must predominate in the materials employed for construction.

The increase in overall dimensions of giant aeroplanes, for reasons which we have previously discussed, is not likely except in the far distant future to be a bar to progress.

The two principal reasons underlying the failure of previous and existing "giant" machines have been, in the case of one "type," due to excessive head resistance resulting from the lateral distribution of motors *exposed* to the wind; in the case of the other "type," due to *structural* limitations arising out of the excessive concentration of weights in the centre of the machine. We are now, however, in a position to avoid both these faults by regulating the weight distribution through the medium of fuel stored inside the wings, and to retain at the same time the combined advantages of both "types."

By the adoption of a bold policy in aeroplane design, by discarding existing standards in relation to factors of safety, and by abandoning any attempt at enlargement on previously accepted lines, we can obtain in "giant" aeroplanes an "over-all efficiency" equal to, if not exceeding, that possessed by the smaller machines of the present day.

In advocating, on account of fundamental considerations, the adoption of the "cantilever wing," we are not necessarily advocating the employment of a monoplane design. The arrangement and disposition of the supporting surfaces depends too much upon individual circumstances to allow of a limiting definition. "Cantilever wings" have been successfully employed in monoplane and also in biplane designs. The system is, in fact, applicable to either mono or multiplane structures, as the requirements of design may dictate.

The Power Plant.

The success of every aeroplane is intimately connected with the choice, installation and arrangement of the power plant. Giant machines form no exception to this rule, and indeed have in the past only served to emphasise its vast importance. The whole question of the power plant and its installation contains, in other words, the key to the achievement of the practical success and the military efficiency of every aeroplane.

Future "giant" machines demand the employment of aviation engines developing the maximum horse-power it is possible to obtain from a single motor. Since real "reliability" can be obtained only from the certain and continuous working of the individual aeroplane motor, so the number of motors to be employed should never exceed the maximum *minimum* which we have previously determined upon as the necessary military compromise in the form of a concession to possible mechanical derangements. Only when the required total horse-power cannot be obtained within the specified limited number of motors can this minimum be justifiably exceeded.

The real significance of these vital facts may be summed up in saying that the employment of a small number of high powered engines guarantees a success which cannot be approached by the use of a large number of low powered engines.

In aircraft, as in all other military matters, "complication" is the grave of efficiency. The ideal engine installation for giant machines must be generally, and throughout all its details, conspicuously simple. Accessory and additional mechanical contrivances, such as "shaft drives"—the presence of which is alien to practical efficiency and simplicity—must find no place in the military "giant" machine.

Such gearing as cannot be avoided, namely, that required for reducing the revolutions of the propeller shaft, must be chosen with regard to the special

circumstances of each individual case. This " reduction gearing " should be, for the sake of simplicity, incorporated in the engine unit itself.

The engine for military giant machines must of necessity be economical in fuel consumption.

In addition, the motors should be designed to give full power at high altitudes by the adoption of the " super " compression type of engine in conjunction with a " fool-proof " fuel control mechanism.

Propeller Arrangement.

While the question of propeller arrangement has been in the past one of some considerable difficulty, principally on account of the large number of motors employed, the future machine with a small number of motors will not be under the same disadvantage and special consideration need, therefore, no longer be given to this difficult problem. It is perhaps as well to mention that the adoption of the " super compression " system in an aeroplane motor allows the engine designer to adjust the number of revolutions corresponding to " full power " at the various altitudes in such a way that, at any rate for some time to come, the introduction of " variable pitch " propellers will be unnecessary and another complication be thereby avoided.

Present Possibilities.

Without in any way drawing upon resources of imagination it is possible to say definitely that immense improvements in the design, construction, " performance," general utility and efficiency of the " giant " machines are within the reach of immediate achievement. With the information already available in Entente countries, and the additional experience gained at the expense of Germany, the development of new " giant " aeroplanes can proceed without undue expense on lines which, backed by actual experiment and previous experience, cannot but ensure a full measure of success. Moreover, it is not necessary that the dawn of a new era in giant aircraft should await the birth of some unknown or novel principle; the past has furnished all the information necessary for the eclipse of present achievements.